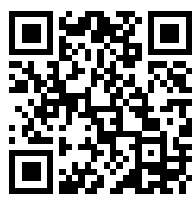
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MASTERS OF SCIENCE AND INVENTION

BY
FLOYD L. DARROW



NEW YORK
HARCOURT, BRACE AND COMPANY

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PREFACE

Masters of Science and Invention offers to the lay reader a simple account in biographical form of the development of scientific achievement from early times to the present day. No knowledge of the laws of science and their manifold applications is even approximately complete without acquaintance with the outstanding figures who have made possible the age in which we live. But the busy reader does not have time to peruse long and often tedious volumes, to obtain this information. Many readers do not know how and where to find it. Even if the names are known, an encyclopedia will give only a bare recital of facts. The human interest features are all omitted. The romance of science and invention is lacking.

This volume not only attempts to humanize science, but gives an accurate and comprehensive outline of its salient features. Each chapter is an essay in itself, and while the chapters follow in general the chronological sequence of events, they may be read in any order. No single story will require more than thirty minutes for its reading. The book is preëminently the general reader's guide to the historical development of scientific fact and theory.

FLOYD L. DARROW.

Brooklyn, N. Y.

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CHAPTER I

GALILEO AND HIS PREDECESSORS

First among the masters of science and invention to catch the true spirit of modern research was the Italian, Galileo Galilei. The supreme purpose of his life was to discover the truth about Nature and her laws. He cared nothing about theory which could not be demonstrated by experiment and observation. Thus we find him, when little more than a youth, disproving from the Leaning Tower of Pisa Aristotle's century-old myth concerning the time of a falling body. But to understand this man and his work we must silhouette him, so to speak, against the background of the ages.

Particularly did Galileo distinguish himself in the field of astronomy, the oldest and most beautiful of the sciences. Even when the curtain rises on the early civilization of the Nile valley, we find the ancient Egyptians following the movements of the heavenly bodies and reckoning time by observation of the sun. The coming of the Nile floods, without which agriculture would be impossible in Egypt, coincides with the summer solstice. So striking a circumstance did not fail to challenge the attention of these observers. The first linking up of astronomical events with the natural phenomena of the earth determined

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the length of the Egyptian year, which from the earliest records that have come down to us, dates from the summer solstice. Even the pyramids, those mighty monuments to the mechanical genius of this early people, were arranged with definite regard to the point at which the sun rises on this most important day of the year. The Egyptians constructed theories of the universe, too, crude products of ignorance and superstition, as befits an infant race making the first tiny explorations of the infinite depths of space.

The Babylonians, extending the knowledge of those pioneer observers of the Nile valley, gave us the week of seven days, the division of the day into hours and the year into months. Just as the sun had been the chief object of interest to the Egyptians, so was the moon to the Babylonians. Its circuit of the heavens gave them their month, and twelve of these they called a year. The Chaldean shepherds, watching their flocks by night and gazing at the stars as a pastime, discovered those wanderers of the heavens, named for that reason planets. Why planets change their positions with reference to the other stars, why the light coming from them does not twinkle, the shepherds could not tell. They saw the nightly rising and setting of the moon and stars, and in common with the view that prevailed for centuries, they regarded the earth as the center of the universe, with the other heavenly bodies at no great distance away and revolving around it once in each twenty-four hours. A natural view, this, and just the one that we ourselves should have taken had we been living at that time.

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Our superior wisdom of today is due to our rich heritage from the past.

The Greeks, that intellectual race of philosophers who carried the learning of the East to the western world, made contributions to this earliest of the sciences, astronomy. They gave to the world Aristarchus, the first notable astronomer of antiquity. Although it is probable that Pythagoras before him had expressed the opinion that the earth is round and revolves about the sun, it remained for this really great Greek astronomer to put forth such a theory, based upon actual observations. Seventeen centuries before the time of Copernicus, Aristarchus proposed a theory of our solar system practically identical with that of today. By sound geometrical methods, he had measured the relative sizes of the sun, earth, and moon. Although his numbers were inaccurate, he saw that the sun was many times larger than the earth and at a great distance from it. For the first time in history, he pointed out the absurdity of making the sun revolve about the earth and traverse such an immense orbit in twenty-four hours. This "Copernicus of antiquity" also taught that the moon shines by reflected light and revolves about the earth. Unfortunately, Hipparchus, his successor, although contributing much to our knowledge of the heavens, rejected this new theory of the solar system, and the world had to wait nearly two thousand years for Galileo to prove its truth.

Who has not heard of Ptolemy, that popularizer of ancient astronomical beliefs, and the perpetuator of

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a false system which held sway for centuries? This Alexandrian astronomer so firmly established the notion of the earth as the center of our solar system that it persisted all through the Middle Ages. By an ingenious but inexplicable system of "epicycles," he accounted for the varying speeds at which the sun and planets move in different portions of their orbits. In an age when original thinking was under the ban and the authority of the past sat upon the throne, this idea of the universe satisfied every need and was handed down from century to century without challenge.

Not until the coming of Copernicus, who was born in Prussia shortly before the discovery of America, did the Western World receive the first pronouncement of the system which modern astronomy has established beyond the possibility of doubt. Harking back to the time of Aristarchus, he set forth an explanation of our solar system, which, although imperfect, was essentially the same as we understand it today.

The deep-set prejudices of an age of ignorance and superstition can not be lightly overthrown. Did not the Bible support the Ptolemaic idea of the universe? Even Luther pointed out that Joshua commanded the sun and moon, and not the earth, to stand still. How could it be possible then that the earth revolves about the sun? So great an astronomer as Tycho Brahe of Denmark did not support Copernicus. Brahe did many noteworthy things. For the first time in history he gave serious study to the comets.

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He observed a new star and gave the correct explanation of its origin. He devised a simple means of determining latitude by observations of the stars. But his most important achievement was the training of Johann Kepler, the contemporary of Galileo, and the astronomer who discovered and formulated the laws that govern the motions of the planets.

And now we come to Galileo. Born in Pisa in 1564, educated in the university of his native city, succeeding to professorships in his alma mater and later at Padua and Florence, this Italian scientist loosed the fetters that bound the thinking of his fellowmen to Aristotle and the traditional past. Even as a student, his hatred of the false, and his yearning for the truth brought him into frequent conflict with his professors and the student body. His demand that the principles of natural philosophy correspond with the facts of observation led him repeatedly to challenge the authority of the past. Thus he brought upon himself unpopularity and the title of " Wrangler." Here was the first apostle of the modern laboratory method, and as usual toward men of new ideas, the world did not look upon him kindly. He disturbed men's comfort. He upset their centuries-old beliefs. He made it necessary for them to think. To Galileo a thing was not true simply because it seemed plausible. With him it must bear the test of rigid demonstration.

Aristotle had taught that a body weighing one hundred pounds would fall one hundred times as fast as a body weighing one pound. No one had thought

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to challenge this statement. Aristotle had said so and that was enough. But every schoolboy knows how Galileo, dropping a half-pound weight and a hundred-pound cannon ball from the famous Leaning Tower of Pisa, proved the utter falsity of this contention. Would you not suppose that this striking demonstration of the truth would have brought fame and approval to Galileo? It did not. Reverence for Aristotle and the past was stronger than the desire to know the truth. The students and the professors of the university hissed him and accused him of being a magician. So unpopular did Galileo become that he was compelled to flee from his native city. He took refuge in Padua where he obtained a professorship in the university, and his fame as a lecturer soon brought to him students from every part of Europe.

But it is in the field of astronomy that Galileo did his greatest work. He early became a disciple of Kepler and a convert to the new theory of the heavens. About 1610 he learned of the newly-invented "Dutch telescope," a contrivance by which it was reported distant objects could be made to appear much nearer and larger. In a moment of inspiration it occurred to this philosopher of Padua that this instrument might reveal the mysteries of the stars. He set to work, and placing lenses at either end of a lead tube, soon had a telescope with which he "saw objects three times as near and nine times as large." He quickly followed this with another instrument which magnified objects nearly a thousand times and brought them thirty times nearer.

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With it Galileo swept the heavens and in so doing expanded the tiny world of the ancients to a universe of vast extent. To his amazement he discovered that he could count ten times as many stars as were visible to the unaided eye. Contrary to the common belief of that time, the stars were not all equidistant from the earth. With this first glimpse of the starry depths the imaginary celestial sphere of his predecessors vanished. Turning his "optic tube" upon the beautiful Milky Way, Galileo resolved this hazy band of mellow light into myriads of faint stars at such stupendous distances as to be indistinguishable without optical aid. Under the magic eye of this new invention worlds without end sprang into view. Venus was seen to pass through phases similar to those of our moon. Thus did he obtain convincing proof that the planets, unlike the stars, are dark bodies shining by reflected sunlight. Our own moon, the most beautiful object of the heavens, disclosed a surface scarred by rugged mountain ranges and pitted with volcanic craters. Disquieting, indeed, was this discovery to the Aristotelian idea, which held the moon and planets to be perfectly smooth spherical bodies.

Innumerable wonders seemed to lie within the uncanny vision of this simple astronomer. The heavens appeared as an open book. The crude speculations of ignorance and superstition disappeared as the mist before the sun. The world grew in mental stature.

But a still greater discovery remained. One evening, as Galileo pointed his telescope toward the planet Jupiter, he brought to view a miniature solar system.

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Here was a huge planet and near by were four tiny "stars." Galileo watched these "stars" from night to night and learned that they circled about the planet, exactly as our moon circles about the earth. But more than that, the revelation gave striking confirmation of the truth of the Copernican theory. Did not the planets revolve about the sun, just as these moons revolve about Jupiter? The phases of Venus had proved this to be true for one planet, and now the last lingering doubt as to the motion of the others disappeared from Galileo's mind.

Not content with these explorations of the night-time skies, Galileo turned his attention to the sun itself. His observation was rewarded by the detection of a dark spot, a seeming blemish, upon the surface of that giant luminary. He noticed that it changed shape, suggesting changes in the substance of the sun itself. Continued observation showed that the spot returned after a period of twenty-four days, thus proving that the sun rotates on its axis. Here we have the first telescopic discovery of a sunspot, one of those gigantic whirlpools of solar activity so intimately associated with electrical disturbances upon the earth, but still presenting much of mystery.

But Galileo lived in the day of the Inquisition. The superstitions that beclouded the minds of men could not be dispelled as easily as were the astronomical mysteries under the spell of his magic tube. The Church still clung to the ancient Ptolemaic belief. The Bible was thought to teach that the earth is immovably fixed in the center of the universe. Giordano

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Bruno, in the year 1600, had been burned at the stake for teaching contrary views. Galileo was warned to keep silent. Still he prepared his famous work, setting forth in the form of a dialogue the overwhelming proof of the Copernican theory. True, Galileo faithfully presented both sides, but the ancient system of Ptolemy completely disappeared before the irresistible logic of the new discoveries.

Angered at this bold attack upon the citadel of religious authority, the Pope summoned Galileo to Rome. He was now an old man, nearly seventy. Sick and feeble, he made the journey with great difficulty. Arrived at the Holy City, this prophet of a new age was treated with the utmost consideration. But the respect was for the man, not for his doctrine. Under threat of physical torture, he was forced to renounce his heretical belief in the earth's motion. His book was suppressed, but too late to prevent the new knowledge from spreading throughout Europe. His purpose has been accomplished. He knew that truth could not long be stifled, and in implicit faith that the new astronomy would very soon vanquish all opposition, he devoted the remaining years of his life to another field of discovery.

To his credit, Galileo attacked the problems of mechanics with the laboratory method. Using inclined planes to diminish velocity, he worked out the laws of falling bodies. For the first time he demonstrated that the path of a projectile is a parabolic curve. With wonderful clearness, he saw the truth of the fundamental laws of motion and came very near to stating

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them. Sitting in a cathedral, he chanced to observe the regular swinging of a chandelier, and as a result of experimentation formulated the laws of the pendulum's motion. He made the first thermometer and attempted to measure the velocity of light.

A many-sided man was the simple scientist of Pisa, Padua, and Florence. Musician, scholar, teacher, mathematician, physicist, inventor, and astronomer, he stands forth now, after a lapse of three centuries, as one of the intellectual leaders of all time. We are today but carrying on the work that he began. When, with each new and more powerful telescope, we push back the frontiers of the universe by a few billions of miles, we thereby only add luster to the accomplishments of this master of the Italian hills.

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CHAPTER II

NEWTON AND EINSTEIN

Bridging the gap from the age of Galileo to the beginnings of modern science, stand the life and work of Sir Isaac Newton. Although two centuries have passed since the time of this astronomer of the British Isles, his name will in future be linked with that of the new genius of science, Albert Einstein. Men have not yet ceased to marvel at the revolutionary ideas of gravitation, space, and time that Einstein has so recently set forth. Yet Einstein only supplements Newton. He does not overthrow him. He gives us new viewpoints. He sharpens our intellects. He makes predictions which the scientists verify with startling accuracy. He explains century-old mysteries. Still, within the limits of our solar system, the laws of Newton are as valid as ever. Whether gravitation be regarded as a mere force, or a "warp in space," the consequences of a fall from the Woolworth Building or the Eiffel Tower will be just as disastrous, whichever viewpoint you take. According to Einstein's own theory, it is all a matter of "relativity" anyway, an idea which we shall make clear a little later.

Newton

Born in 1642, the year of Galileo's death, frail and sickly as a child, Sir Isaac Newton gave no promise

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of the fullness of years which were to crown his active life. Neither did his early work as a student give indication of the achievements that were to be born of his genius. As a lad, he exhibited a strong mechanical bent, but not much aptitude for study. Even at college, when he presented himself for a scholarship, he gave a poor impression of his mental ability. But the study of the geometry of Euclid aroused his interest in mathematics, and soon the intellectual world knew that a sleeping giant had been awakened.

Everyone has heard the story of Newton and the falling apple. In 1666, when only twenty-four, he was driven from London by the Great Plague. As you will recall, seated one day in the little garden of his estate at Lincolnshire, he was aroused from a deep reverie by the falling of an apple. Newton did not, as a result of this incident, discover the force of gravity. That the earth exerts a powerful attraction for objects on and near its surface had been a matter of common experience from the remotest antiquity. It had even been suggested by the Greek philosopher, Anaxagoras, that the same force which attracts objects at the surface of the earth might also hold the heavenly bodies in their orbits. But to no one before had it occurred that this attractive force might be a property common to all matter and might extend its influence to the uttermost depths of space. Much less had anyone dreamed of being able to demonstrate that universal law. In this matchless conception we see the genius of Newton displayed to the full. Like the first sweep of Galileo's telescope across the heavens, it introduced

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men's minds to a hitherto unknown universe of vast extent. It broadened the earth-bound souls of men and gave to all creation a new and larger meaning.

What was this idea, destined, as it proved, to mold the scientific thinking of his own and succeeding generations? Newton, musing over his observation of the falling apple, argued that it would have fallen from a height of fifty yards, of five hundred yards, yes, from the top of the highest mountain. To how great a distance, he asked, did this force of gravity extend? Would it grow less, as the distance from the earth increased? Would it ever cease? How could he answer these questions? Was there no way of testing this matter? Could the force of gravity be made to yield up the secret of its law of action? But wait. Can it be true, he asked, that the same force which draws the apple to the earth also holds the moon in its orbit? A mighty query was this. Imagine yourself asking it for the first time in the history of the race. Then try to realize the feelings of anticipation with which you would proceed to determine the truth or falsity of this momentous question.

How did Newton determine it? He saw at once that, if his idea were true, the moon must be a falling body obeying the same laws that Galileo had discovered a generation before. Yet you may ask, "If this be so, why does not the moon fall into the earth?" Newton answered with the statement of his First Law of Motion. *Every body tends to continue in its state of rest or uniform motion in a straight line, unless acted upon by an outside force.* He considered the

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moon as having a motion of its own, which, should the force of gravity be released, would cause it to fly off into space in a straight line, tangent to the curve of its orbit. The gravitation of the earth, producing an accelerated motion toward its center, together with the moon's own tendency to move with uniform velocity in a straight line, would cause our nearby neighbor to follow precisely the path about us that it has and will, from its beginning to the end of time. Could this idea be true? Was here a heavenly body which constantly falls toward the center of the earth and yet never approaches closer to it? To Newton it was clear as sunlight. Granted the conditions which he had assumed, the thing must be so. To him it was as simple as the whirling of a ball attached to a string. The constant pull of the hand on the string is the force of gravity, and any boy knows that, should the string break, the ball will fly off in a straight line.

Newton's next step was to test his theory. From the known distance of the moon and its rate of motion, Newton calculated the distance that it falls away from a straight line and toward the center of the earth in one minute of time. Although twenty years passed before his final proof, comparing this distance with that required by the law of gravity, he found that the moon is as truly a falling body as was the apple which fell in his garden. As he proceeded with the calculation, and the truth of his great discovery dawned upon him, he was overwhelmed with emotion and compelled to leave the completion of the simple computation to a friend. Well he might be. Here was the first clew

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to an explanation of the motions of the heavenly bodies. Out of the maze of ancient guesswork, interwoven with the discoveries of the new astronomy, he could see emerging a system of perfect law. One more step had been taken toward unravelling the eternal mysteries of the universe.

Kepler had shown the orbits of the planets to be ellipses with the sun located at one of the foci of each. He also discovered the laws governing their motions. It remained for Newton to demonstrate that these motions are the direct result of the gravitation of the sun, just as the motion of our moon obeys the gravitation of the earth. As a result of a prodigious amount of mathematical calculation, he brought under the sway of this law the rising and falling of the tides, and the motions of the satellites, comets, and meteors of our solar system. During the last century, Neptune, the outermost member of our planetary system, was discovered solely through the aid of Newton's Law of Gravitation. A more striking confirmation of the seeming truth of a great principle is to be found nowhere else in the history of science. In more recent times this law has been made to embrace the motions of the stars. For two and a half centuries it held undisputed sway, and even now, for all practical purposes, its dominion is as vast as ever.

EINSTEIN

But how has Albert Einstein, this Swiss Jew exiled now from Nazi Germany and living in America, changed

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our ideas of the universe? What is this strange doctrine which has fallen like a bomb into a peaceful camp, upsetting our orthodox notions of the eternal verities of time and space and spreading dismay among the worshipers of a sacred past? Is this new theory a finespun fiction of the imagination or does it rest upon a solid basis of experimental fact? Abstruse, revolutionary of much that we have been taught to believe, difficult of picturing to the mind's eye, indeed, this new knowledge is. But where the path of truth lies, there must the scientist follow.

The new view of our universe divides itself into two parts. The earlier one was proclaimed in 1905 and has to do with the bewildering paradoxes of relativity. The other is an all-embracing and equally astonishing doctrine of gravitation. Just as the scientists, after three centuries of arduous labor, had placed this old world upon a bed-rock foundation of absolute security, along comes this disturber of universal peace and plunges us once more into the depths of medieval chaos. But when a man makes startling predictions and the scientists verify them almost to the letter, he must be reckoned with. Much as we should like to do so, we cannot sidetrack him.

To make this matter of relativity clear, we shall take a few familiar examples. Let us consider the idea of motion. Einstein says there is no such thing as absolute motion. That is, the motion of a body is always relative to something else. It never proceeds in a perfectly straight line with absolutely uniform velocity. A body falls to the earth, but at the same

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time the rotation of the earth carries it forward at the rate of a thousand miles an hour at the equator, and the revolution about the sun hurls it through space with a speed of eighteen and one-half miles a second. In addition, our whole solar system is moving toward the star Vega with a constant velocity of twelve miles a second. To us this body seems to fall in a straight line, but its path is really a long and complicated curve. Furthermore, the motions of the heavenly bodies are only relative. Were our earth enveloped in a dense mist so that we could not see the sun, moon, and stars, we should never be able to discover any motion. The heavenly bodies move with respect to each other, but there is no means of telling whether there is any absolute motion of our universe through space. If a swarm of bees were flying about inside a large, hollow sphere, there would be relative motion of the bees with respect to each other, but they could never discover whether their sphere were being carried through space. The motion is relative, not absolute. Would there be any sound, if there were no ear to receive it? Yes, and no. It is a matter of relativity. It depends upon your viewpoint. To the physicist the sound waves are there, independently of any ear to hear them. But in the physiological sense there is no sound. When we say that a room is so long, what do we mean? We mean that it is so many yards long as measured by a yardstick, which is just as long as the distance between two marks on a bronze bar at a temperature of freezing water kept in the archives of London. Measurements of every description are

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relative to something else. There is nothing absolutely fixed in the universe. That is Einstein's contention.

Einstein also makes the startling assertion that time and space are purely relative. There is no such thing as empty space. There would be no space, if there were nothing to put in it. So with time. There would be no time, if nothing ever happened. Furthermore, Einstein links space and time into an indissoluble unit. Nothing could exist in space, if there were no time. Just think of it for a moment. Could a house exist in space, if there were no duration of time? Newton and all his followers down to the present day have thought of time and space as distinct and unrelated elements of the universe. But one can not exist without the other. Time is Einstein's fourth dimension. You cannot define an event without locating it in a three-dimensional space and stating its position in a fourth dimension of time. The values that we assign, too, to space and time are wholly relative. If everything in the universe were overnight increased tenfold in size, including our retinas, we could never discover that fact. Our measuring rods and our sense impressions would all correspond with the new order. How do we measure time? By the movement of a hand over a dial and the motion of the heavenly bodies. It is always relative to something else. A minute may sometimes seem an eternity and hours as fleeting seconds. It is all relative to the observer.

Einstein was led to develop his theory of Relativity from a consideration of the famous experiment made in 1886 by Michelson and Morley to determine the

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absolute motion of the earth through space. Because it is unthinkable that light and heat energy should travel in wave form millions of miles from the distant sun and stars to our earth without something in which to travel, scientists have filled all space and the pores of matter itself with a luminiferous ether. This ether was thought to be without weight, and resistless to the motion of the heavenly bodies through it. If the earth, then, has an absolute motion through space, why would it not be possible to measure its velocity, as this fixed ether streams through its pores? The earth revolves about the sun with a velocity of eighteen and one-half miles per second, but does it have an absolute motion through space? To answer this question, Michelson and Morley devised an experiment similar to the case of a swimmer who should attempt to determine whether it takes more time to swim a mile up-stream and back, or a mile across-stream and back. In their experiment the swimmer was a ray of light, part of which was sent a definite distance in the direction of the earth's motion and back, and the other part an equal distance and back at right angles to the former path. By an exceedingly sensitive apparatus, capable of detecting differences of one-twenty-five-millionth of an inch in the path of a ray of light, these observers noted the instant at which both rays of light returned to the starting point.

A simple calculation will show that it takes the swimmer longer to go up-stream and back than it does across-stream and back. But imagine the amazement of Michelson and Morley to find that both rays re-

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turned at the same instant. The experiment was repeated many times and at various seasons of the year, but always with the same result. The motion of the earth, if it has any, seemed to have no effect on the velocity of light. The ether did not seem to drift through the earth, and a previous experiment by Sir Oliver Lodge had seemed to prove that it was not carried along with the earth. Here was an apparent contradiction, a blind alley from which there appeared to be no escape.

At this point Einstein came upon the scene. He put forth the two fundamental propositions, that *all motion is relative,* and that *the velocity of light is independent of the motion of its source.* Both of these had seemed to be confirmed by the Michelson-Morley experiment.

From them Einstein proceeded to draw certain sweeping and disturbing conclusions. We shall state a few of them. The velocity of light is the greatest velocity possible to obtain. A person flying with the velocity of light would never grow old. Were it possible for him to fly with a velocity greater than that of light, he would actually grow younger. A yard-stick moving drectly away from us and flying with this velocity of one hundred eighty-six thousand miles per second would have no apparent length, although to an observer moving beside it, the length would be as great as ever. Were it moving with a velocity of one hundred sixty-one thousand miles per second, its length would shrink to one-half. Were it possible for you to move away from the earth with the velocity

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of light, events on the earth would seem to stand still. Nothing would ever happen. Time would cease to exist. The hands of a clock would never move. Could you move with a velocity greater than that of light, you would overtake the light waves of previous generations, and the panorama of history would be viewed in reverse order. The mass of a body, which we have thought to be invariable, increases with its velocity, becoming infinitely great at the speed of light. Because of these facts, our judgments of motion, time, and distance are relative to the observer. The events of our earth to an observer on an airplane moving by us with half the velocity of light would have very different values from those which they have for us.

But let us remember that at no velocities possible to obtain on this planet will the measurements of time, space, and matter vary in the slightest degree from what they appear to be under the older physics of Newton and his successors. The differences exist, but to detect them would require measuring instruments a million times more accurate than any which it is possible to make.

But what of Einstein's new view of gravitation? It will be to his everlasting credit that for the first time in the history of men he considered the possibility of another explanation of why bodies fall to the earth than that of Newton. Why assume a mysterious force of gravitation? Is there no other way of accounting for the apple's fall? Einstein said yes.

Suppose you are sitting in a motionless room in

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empty space, millions of miles from any attracting body. You will have no weight. Your hat will not press down upon your head. Your body will exert no pressure upon the seat beneath you. A ball released from your hand will not fall. A spring balance will register no weight. Then suppose that the room begins to rise with an accelerated velocity exactly equal to that of a falling body at the surface of the earth. Immediately you will have weight and exert pressure upon the floor. The ball will fall. The spring balance will measure the weight of any body to which it is attached. The effects which you observe will be precisely those of gravitation. But you will be unable to discover by any possible means whether it is some mysterious force of gravity that is producing these effects, or the accelerated motion of the room in which you are seated. So with the earth and our solar system.

In his revolutionary ideas of gravitation, Einstein starts with the proposition that wherever there is matter, space is curved. This seems absurd. How can space be curved? Is it not possible to draw straight lines in space? Does the straight-line, three-dimensional geometry of Euclid no longer hold in our universe? But did you ever observe the objects of a room as reflected in a slightly concave mirror? In it the straight-line space of our room has been warped and distorted. Just so, Einstein considers that the four-dimensional time-space of our universe is warped in the vicinity of a great mass of matter like a planet or our sun. How this may be, it is difficult to picture

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to the imagination. Our nearest approach to it is to think of intelligent two-dimensional beings placed upon a sphere. They have no knowledge of a third dimension. They regard the surface of their universe as flat. Parallel lines will never meet and no straight line will ever return to its starting point. The introduction of a third dimension will be as upsetting to their fixed notions of space as is Einstein's curved space view to our ideas. But just as these two-dimensional beings would have false ideas of their world, so may we be wrong and Einstein right.

What has all this to do with gravitation? Just this: that a planet may follow an elliptical path about the sun and an apple fall to the ground, not because of any mysterious force of gravitation, but because these paths are the lines of least resistance through a space that has been warped and curved by the presence of a large mass of matter. If we should find that a marble placed at any point near the walls of an apparently level floor always rolled to the center of the room, either one of two possible explanations might be given. There is some force attracting the marble, or the floor is curved. So with gravitation. Either there is some force of attraction common to all matter, or space is curved. Newton took the former view. Einstein has chosen the latter.

Is there no way of testing this matter? Yes. Einstein says, if my view is correct, if space is curved, then a ray of light from a distant star in passing by the sun ought to be bent out of its straight line path. On May 29th, 1919, two British expeditions, one to

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Brazil and the other to the west coast of Africa, took photographs of the sun and the stars at the time of a total eclipse. These photographs were compared with others taken several months later, when the sun was not in that portion of the heavens. As a result, it was determined beyond the possibility of doubt that the starlight had been shifted, and shifted very nearly the number of seconds of arc that Einstein had predicted it would be. Here was an astronomical triumph of the first magnitude. It has been surpassed by no other and equaled only by the discovery of Neptune. Preliminary reports of more recent observations have also confirmed Einstein's view.

Yet this was not all. From his theory that the mass of a body increases with its velocity, Einstein gave a perfect explanation of a hitherto unaccountable discrepancy in the orbit of Mercury, which had puzzled astronomers for generations.

Were it not for these two remarkable experimental proofs of this new theory, we should long since have consigned Einstein and his revolutionary ideas to the realms of pure speculation. But when a scientist's theories square with the observed facts of Nature, the world cannot ignore him. In the centuries to come it will be to the glory of this physicist from across the seas that he has taken us a long way nearer to an understanding of the ages-old mysteries of time and space. To the end of time the names of Newton and Einstein will stand as symbols of two of the mightiest intellectual achievements of the race.

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CHAPTER III

FROM ALCHEMY TO MODERN CHEMISTRY

Nowhere else in the vast domain of natural science do we find a more interesting field than that of chemistry. From the days of alchemy to the present moment the lure of chemical discovery and the deep mysteries of the atoms have held in rapt fascination the imagination both of the early peasant and the modern scientist. The glitter of pure gold and the inexhaustible wealth of Nature's treasure house have led men in every age to search untiringly for the secrets of energy and matter. Along the pathway of their discoveries we trace the material, and to a large extent the intellectual, progress of the race.

But the early knowledge of chemistry was wholly accidental. Not until modern times has it become a science. In the gray dawn of history we find applied chemistry the handmaid of industry, even as she is today. Without this development of hand and brain, the works of architecture, the weapons of warfare, and the utensils of the domestic arts would have been impossible. Among the Egyptians, Phoenicians, Jews, and other ancient peoples the metallurgy of the simple ores, viz.: gold, silver, copper, iron, lead, and tin, was a highly perfected art. The "bronze age" of primitive history bears testimony to an early knowledge of

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metallic alloys. The manufacture of glass and its artificial coloring tell us of the marvelous skill of these early workers, preceded by long centuries of experiment and toil. Among the earliest chemical processes were the preparation of soaps, dyes, and pigments, numerous medicines, oils, and perfumes. A knowledge of fermentation was possessed by the most primitive peoples.

Born in Egypt and carried by the Arabs into Spain and Central Europe, alchemy, all through the Middle Ages, enchanted with its mystic spell every class of society, and in its withering blight delayed for a thousand years the beginnings of real chemistry. The sway of the alchemist was absolute. Working over his pots and retorts in crude laboratories and dark caves, shrouding in deepest mystery his secret activities, this blind groper after that will-o'-the-wisp, the Philosopher's Stone, shaped for many centuries the course of all things chemical. The fortunate possessor of this magic substance might command those two highest goods — wealth and health — and also with its continued presence, nobility of character and spiritual refinement.

Many imposters rose to prey upon the credulity of king and prince and separate them from their treasure. It is related that an alchemist, who claimed to have found this coveted Essence, was one day giving a dinner to some of his friends. In the midst of it he narrated a personal experience, which had occurred eight hundred years before. Noting the astonishment with which this tale was greeted, he turned to his

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valet and said, "John, is not that true?" Whereupon the faithful servant replied, "Master, you forget that I have been in your service but five hundred years."

Although alchemy added very little to the knowledge of chemical industry, it did represent one great gain. It gave a tremendous impulse to the actual working with substances. As a result, skill in manipulation was acquired, and also a knowledge of fundamental chemical processes.

With the decay of alchemy the chief aim of chemistry became, in the words of its leader, Paracelsus, "not to make gold but to prepare medicines." For two centuries the apothecary shops of Europe were transformed into research laboratories, in which, under the stimulus of preparing new remedies, many important discoveries were made. In their haste to test the curative virtues of these drugs the most violent poisons were freely used and, as a result, many a patient died a martyr to the cause of science.

Thus slowly, painfully, blunderingly did the science of chemistry emerge into the sunlight of modern triumphs. It was a glorious dawn that awaited the early workers in this vast domain. New paths opened on every side. Innumerable secrets were ready to yield their meanings. After the black night of medieval ignorance and superstition, a golden age of chemical discovery was about to follow. Realms of unexplored truth beckoned the investigator. With envy we look back today upon this paradise of untrod chemical fields.

Four chemists — Priestley, Scheele, Cavendish, and

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Lavoisier — first among men of science, studied chemistry for its own sake. To them the pursuit of truth was the most important quest of the human mind. Its practical application in the arts and industries was of minor consequence. This has always been the spirit of true scientific research.

Joseph Priestley

Many are the discoveries to the credit of that English clergyman and chemist, Joseph Priestley, whose early work marks the borderland between the old chemistry and the new. His experiments had to do chiefly with gases. Near his parish was a brewery from which he obtained carbon dioxide and named it "fixed air." Gases were in those days known as "airs" of various sorts. Being poor, he was compelled to devise his own apparatus, and as a result, we owe to him the pneumatic trough in which gases are collected, besides other ingenious devices. His discoveries were due to his originality and skill as a manipulator no less than to his fondness for experimentation. Giving a careful study to the properties of carbon dioxide, Priestley learned of its solubility in water and laid sure claim to lasting affection by first suggesting the use of soda water as a beverage.

Learning of the newly discovered gas, hydrogen, known then as "inflammable air," he immediately began to experiment with it. To the little scientific world of that day the discovery of a new element was hailed with all the enthusiasm with which we greeted

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the birth of radium at the beginning of the present century. A substance is recognized by its properties. Therefore to learn the nature of this substance, Priestley enclosed some of it in a glass cylinder together with lead oxide and applied heat. Imagine the privilege that would be yours and the eagerness with which you would proceed, if it should fall to your lot to investigate the properties of a new element. Presently, as the heat became more intense, Priestley observed that the mercury, over which he had placed the hydrogen and oxide, began to rise in the cylinder and in place of the red oxide of lead, metallic lead began to appear. At the same time water formed on the cooler portions of the cylinder. Simple as this chemical action now seems, he was unable to explain the facts correctly at that time. It had to wait for new discoveries, chief among which Priestley himself was destined to make.

The principal obstacle to an understanding of this and many other facts of chemical observation was a false theory of combustion, or burning, which had prevailed for a century. According to Georg Ernst Stahl, physician to the king of Prussia, all combustible substances contain a common principle, called *phlogiston,* which escapes on burning. Substances that almost entirely burn up, like coal, were regarded as nearly pure phlogiston. Indeed, hydrogen was thought to be the stuff itself. Metals were not elements, but compounds, and when heated in the air, phlogiston escaped. That the product of heating a metal in the air weighs more than the metal was entirely disre-

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garded, or explained on the supposition that phlogiston possesses the property of levity, or negative weight. Upon losing this buoyant influence, the metal should weigh more. Although a false one, this theory did seem to explain a large number of facts, and modern chemistry found it difficult to shake off its paralyzing grip. For Priestley it completely masked the correct explanation of most of the chemical processes which he observed.

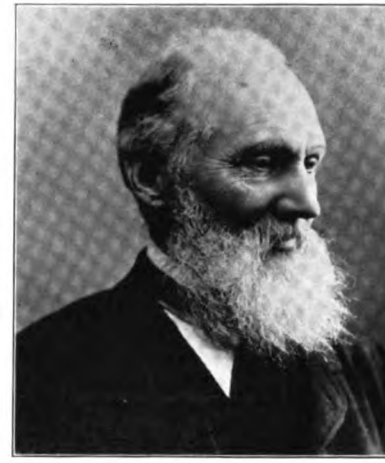
But the fame of Priestley will rest upon his discovery of oxygen, which he accomplished on August 1, 1774, by heating red oxide of mercury with the aid of a twenty-inch burning glass. This method of obtaining heat illustrates the crude laboratory equipment with which those early chemists were compelled to work. Alcohol lamps were unknown and the inventor of the Bunsen burner not yet born.

As the temperature rose, a mirror of mercury appeared on the walls of his generating apparatus and a gas was driven off, which he collected over water at his pneumatic trough. Upon introducing a candle into this gas, Priestley found that it supported combustion with great brilliancy. Therefore, in accordance with the false phlogiston theory of combustion, he called it "dephlogisticated air." His notion was that having been robbed of its phlogiston, this gas absorbed phlogiston from a burning substance, as a sponge takes up water. A mouse placed in the gas became more lively, and he himself was greatly invigorated by breathing it. He soon came to the conclusion that air was a mixture of his newly discovered gas and what he called

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MORSE



LORD KELVIN



NEWTON



EINSTEIN

From Slosson's Easy Lessons in Einstein



CAVENDISH

From Moore's History of Chemistry



ORVILLE WRIGHT

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DUMAS



BERZELIUS



LIEBIG



STEPHENSON



MENDELÉJEFF

From Moore's History of Chemistry



DALTON

From Moore's History of Chemistry

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"phlogisticated air," now known as nitrogen, in the ratio of one to four.

Priestley discovered and experimented with a number of other gases, including carbon monoxide and the anaesthetic, nitrous oxide. Although surrounded with an abundance of evidence to the contrary, Priestley obstinately persisted in holding to the phlogiston theory to the end of his days.

Having aroused the anger of his fellow-countrymen, because of his views on the French Revolution, Priestley migrated to Pennsylvania, where he passed the last decade of his life and today lies buried on the banks of the Susquehanna River. A memorial service was held there in 1904 to observe the centenary of his death.

Karl Wilhelm Scheele

Karl Wilhelm Scheele, in his short life of forty-three years, made discoveries which have stamped him as one of the most original investigators of all time. He was a pioneer in every field of chemistry, and his accurate and masterly researches did much toward laying deep and sure the foundations of the modern science.

Scheele was born at Straslund, Sweden, in 1742, the seventh in a family of eleven. He early displayed a strong bent for science, and at the age of fourteen was apprenticed to an apothecary in Gothenburg. It is a fact worthy of special note that this great chemist was a "self-made man." Denied the advantages of a

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university education, the apothecary shop became his school. In it he experimented with ceaseless energy, providing himself with such books and apparatus as his limited means made possible. Fired with a passionate desire for truth, scarcely equaled elsewhere in the whole history of science, this Swedish chemist possessed a genius for discovery. Independently of Priestley and at least two years earlier, he discovered oxygen, and prepared it in a variety of ways, but failed to publish his results until a later date. He was the first to prepare chlorine, so important in bleaching, and the first of the poisonous gases used in the World War. He studied the compounds of tungsten and molybdenum, two elements of vast importance in the manufacture of steel, and the latter priceless as the ideal filament in the electric lamp. He experimented with hydrogen sulfide and the deadly gases, arsine and prussic acid, even describing the odor and peculiar taste of the latter. How he survived this experience, no later chemist has been able to imagine. In all of this work he devised much of his own apparatus and perfected many new methods of analysis. He was the first great master of qualitative analysis, and it is, indeed, due to this insatiable desire to know the properties of substances and to prepare new ones that his discoveries were made. In the realm of organic chemistry he made numerous brilliant discoveries, and may be regarded as the virtual founder of this important branch of the subject.

Beset with poverty until the closing years of his

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life, Scheele worked at all times under difficulties. Yet he lived to see his name honored in every capital of Europe, and his discoveries known wherever chemistry was studied. Intent more upon preparing new substances than upon the explanation of chemical processes, Scheele never came to a true understanding of the fundamental process of combustion. He lived and died a staunch phlogistonist. Cut down in his prime, the untimely death of this first great research chemist robbed the science of that day of its most noble figure.

Sir Henry Cavendish

In Sir Henry Cavendish we find the most eccentric genius who ever devoted his life to the cause of science. Hating notoriety as he would a plague, shunning all intercourse with his fellowmen, cold and austere to the end of his days, wholly lacking in the genial warmth of human sympathy, yet unsurpassed in his breadth of knowledge and depth of learning, this gifted recluse loved truth for truth's sake as few other men have done. He seemed to regard it as his life work to discover as many of the physical facts of the universe as might be possible within his span of three score years and ten. Yet it was always to satisfy his own selfish thirst for knowledge, and not at all for the benefit of science. He did not wish his discoveries to be published, and many of them were unknown until after his death. Although one of the wealthiest men in England, money had no value for

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him. At the time of his death he was the largest stockholder in the Bank of England, but he had repeatedly threatened to take his money out, if the bank did not cease bothering him about it. One day a committee of citizens waited upon him and asked if he would not subscribe to some worthy cause. Absentmindedly, doubtless absorbed in some scientific problem, he inquired if ten thousand pounds would be of any value, and quickly wrote a check for that amount, probably thinking it a small price to pay if they would but leave him undisturbed. On one occasion, having been induced to attend a social function in his honor at the home of Sir Joseph Banks, he precipitately fled from a back door, when he learned that a foreign guest wished to question him concerning his discoveries. Even in his hour of death, he wished to be alone and savagely ordered his servant to depart and not to return until the end had come.

Cavendish's first work was on the subject of heat. He improved the mercury thermometer and determined the freezing point of mercury. To him we also owe the first use of this liquid metal over which to collect gases that are soluble in water. He studied carbon dioxide and for the first time correctly explained the cause of the boiler scale of carbonate of lime which forms on the inside of tea kettles and steam boilers. But his most notable achievement is probably the discovery and exhaustive study of hydrogen gas, which he made in 1766. The combustion of this highly inflammable gas with the formation of water, led him to determine with great accuracy the composition of

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water and to disprove the ancient idea that this substance is an element. With a skill which even now challenges the admiration of the modern scientist, Cavendish determined the percentage composition of the atmosphere with a precision scarcely excelled by the most refined of present methods. By passing electric sparks through air confined over water, he obtained nitric acid in solution, and from the small residue of air, which he could never make disappear, he came close to the discovery of the rare gases of the atmosphere, one of the most notable achievements of the following century. By an ingenious method he weighed the earth, and determined its specific gravity, or how many times heavier it is than an equal sphere of water, obtaining a result practically identical with what the modern astronomer has determined it to be.

Although Cavendish did not die until 1810, like Priestley and Scheele he clung to the last to the discredited phlogiston theory of combustion.

Antoine Laurent Lavoisier

Modern chemistry, free from every vestige of alchemy and the false phlogiston theory of combustion, dates from the researches of the French chemist, Lavoisier, who possessed remarkable ability in interpreting the facts of scientific discovery.

Born of a noble and wealthy family, Lavoisier was given every advantage of education and travel. Having received excellent training in mathematics and

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physics, as well as in botany, mineralogy, and geology, he early decided to devote his energies to the cause of science. But it was as a physicist, with the physicist's delight in quantitative work, that Lavoisier approached the subject of chemistry. He did not add much in the way of new discoveries, but, taking the rich store of chemical information handed down by the phlogistonists, he explained the facts observed, and the chemical processes involved, with a keenness of insight and a breadth of understanding never before known. It will forever stand to his credit that he attacked the problems of chemistry with the balance, and sought to show that nothing is either gained or lost in a chemical reaction. To him we owe the first classic proofs of the fundamental law of conservation of matter, i.e., that *matter can neither be created nor destroyed.*

His first important contribution to this end was to explode the alchemistic idea that water can be changed into earth. He boiled water in a sealed glass vessel for one hundred days and found, as he expected, that the vessel and contents had not changed in weight. Nothing had been gained from the fire. The empty vessel had lost in weight, but the residue from the evaporated water exactly equaled this loss, showing that the apparent formation of earth had been due to the solution of glass by the water.

But we remember Lavoisier chiefly for his accurate explanation of combustion and oxidation. From Priestley he learned of " dephlogisticated air " and its

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properties. He repeated Priestley's experiments and thereby gained the clew he needed for the explanation of the fact, which he had verified by numerous tests, that a metal gains in weight when heated in the air. Lavoisier had heated a weighed quantity of tin in a sealed glass vessel, thus changing a portion of it into a gray powder. Although he found that the vessel as a whole had not gained in weight, air rushed in when he opened it. This indicated that the tin had united with something in the air. What this something was he did not then know. But he weighed the vessel and contents again, and found that the increase in weight was exactly equal to the weight that had been gained by the tin. Lavoisier therefore concluded that Priestley's newly discovered gas was the supporter of combustion, and the cause of the increase of weight when metals are heated in the air. This was the most important chemical relationship that had been discovered up to that time. It dealt a death blow to the phlogiston theory, and laid the foundation stone of the wonderful progress in chemical science that soon followed.

Since Lavoisier incorrectly assumed this new gas to be an essential constituent of all acids, he named it "oxygen," which means acid-former. He also gave names to hydrogen and nitrogen. His "Elementary Chemistry" was the first rational textbook on the subject ever written. It wrought a chemical revolution and set the new-born science of chemistry on the broad highway to modern achievements.

Had it not been for his political activities, Lavoisier

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might have rendered still greater services to the advancement of science. Unfortunately he had incurred the enmity of the Revolutionary Government and was guillotined in 1794. It was a mad act of leaders, drunk with power; it was even more flagrantly a crime against science itself.

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CHAPTER IV

FOUNDERS OF THE TEXTILE INDUSTRY

James Hargreaves

Spinning and weaving, beginning as a domestic art and growing into a great industry, have been fundamental to the progress of civilization ever since the race emerged from the cave-man stage. Hand in hand with the metallurgy of the simple ores and the arts of pottery and architecture, spinning and weaving have been essential to the satisfaction of personal comfort and to the development of men's aesthetic tastes. The familiar domestic picture of the spinning wheel beside the fireplace was characteristic of every rural household in this country up to but little more than a half century ago. Even at the beginning of our Civil War, "homespun" clothes were the rule, not the exception among the country population. The wool or flax was first carded to straighten the fibers into long slender "slivers" about the size of a candle wick. Then, either by the spinning wheel or distaff and spindle, it was drawn out and twisted into fine, firm-textured thread. Finally it was woven into cloth in hand looms. Thus by slow and laborious methods were the textiles of our forefathers manufactured.

In the work of weaving two sorts of threads are employed, the "warp" and the "weft." The warp-

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threads lie parallel to each other and run lengthwise of the weaving-frame. The weft-threads, or "filling," are passed alternately over and under the warp, row after row, until the cloth is completed. To obtain the warp and weft in sufficient quantity, required a prodigious amount of hand spinning, and toward the middle of the eighteenth century had become a problem of constantly increasing difficulty. But as is likely to be the case, just at this crisis a number of revolutionary inventions appeared in rapid succession.

The first of these was the spinning-jenny, invented by James Hargreaves, an illiterate spinner, living near Blackburn, England. Hargreaves must be credited with the first practical mechanical device to take the place of the ancient spinning-wheel. He took out his first patent in 1770, although he had perfected his machine some years before. The spinning-jenny was designed for use with cotton fiber. After the coarse fleecy rolls from the carding device had been slightly drawn and twisted, the spinning-jenny took them and reduced them to yarn. It is said that Hargreaves received his idea from seeing an overturned spinning wheel upon the floor and noting that both wheel and spindle continued to revolve with the spindle in a vertical instead of a horizontal position. Acting upon this suggestion, he devised a frame carrying a number of vertical spindles and operated by a wheel turned by hand. With it he was able to spin about a dozen threads at once, in the same length of time and with no greater effort than were required by the older method to spin a single thread. By constant improve-

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ment Hargreaves was soon spinning thirty threads at a time.

This device was a marvelous time-saver for those days. It did not change the principle of spinning, but simply enabled the operator to draw and twist a large number of threads at once. Just as before, the drawing was done by hand and the final twist was given by a revolving spindle. As long as possible, Hargreaves kept his invention secret. He employed it in his own household for spinning weft for his family's needs. But when rumor had spread abroad of this wonderful device, the cotton-workers of the neighborhood attacked his shop, destroyed his spinning-jenny, and drove the inventor from his home. These ignorant people looked upon any labor-saving device as an enemy of the worker. It seemed to them inevitable that every such machine would diminish the amount of labor and throw men out of employment. They could not see that by decreasing the cost of production a larger market would be obtained, requiring larger factories and more workers. Thus Hargreaves fell a victim to the ignorance of his time. He fled to Nottingham, where he secretly made more jennies and used them in spinning yarn for the hosiery manufacturers of that vicinity. At length the value of his invention became appreciated and he was recognized as a benefactor of his fellows. Still he died without having received the financial reward that was his due.

Although it was the first great invention of the textile industry, the spinning-jenny had defects. Only certain kinds of threads could be spun in it, and the

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cotton fibers required careful carding before they could be used. Also, it was impossible to spin yarn strong enough to be used for the warp. Only the weft could be spun in it. Another invention was needed and it was not long in forthcoming.

Sir Richard Arkwright

It fell to Richard Arkwright, an untutored barber of Lancashire, England, to take the next step in the forward movement of the textile industry. He invented a machine that was able to spin warp-thread as well as weft. Arkwright was the youngest in a family of thirteen. His parents were poor. He was born in 1732, in the center of the cotton-manufacturing district, and from a lad was familiar with the spinning and weaving processes then in use. About 1760 he forsook the trade of barber, to which he had been apprenticed, and became a dealer in hair, increasing his revenue considerably by the use of a secret process of dyeing. One day he chanced to see a red-hot bar of iron being rolled out into a long rod by repeated passages between heavy corrugated rollers. This set him to thinking. Why, he asked, cannot a similan method be employed for spinning cotton warp? He began to experiment. The result was the "spinning-frame," which he patented in 1769.

The spinning-frame consisted essentially of two sets of rollers, through which the long fleecy "slivers" of carded cotton were passed. The lower roller of each set was furrowed, or fluted, lengthwise, while the upper

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rollers were covered with leather to enable them to take hold of the cotton. By revolving the second set of rollers at a speed several times greater than that of the first, Arkwright was able to draw the threads into any desired degree of thinness or hardness. Threads strong enough to be used for the warp were now easily obtained, and in addition a large number of threads could be spun at the same time. Furthermore this machine was adapted for use with either water- or steam-power.

Having been warned by the experience of Hargreaves, Arkwright proceeded to Nottingham with his invention, and endeavored to interest some capitalists in the building of a factory. For a time he was unsuccessful, but at length Jedediah Strutt became convinced of the possibilities of the invention and assisted the inventor to establish his first mill. It was run by horse-power, but proved so expensive that Arkwright soon built a new mill at Cromford, which he operated by water-power. For this reason his device became known as the "water-frame." He constantly made improvements on his original designs and in 1775 patented a number of new devices. His factories began to multiply and in a few years, the man who a short time before could not appear to vote as a burgess of his town until he had been given a suit of clothes, became a substantial and prosperous citizen. One factory which he established in the enemy-stronghold in Lancashire was destroyed by a mob, in full view of the magistrates and police.

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But he had now grown so prosperous that the destruction of a single factory was not a serious loss.

Still Arkwright was to be denied the unmolested right to his invention. The cotton-manufacturers formed a conspiracy to rob him of the fruits of his patents. Either they must pay Arkwright royalties for the use of his patents or allow him to take away their market, by the production of cheaper and better goods. They proposed to do neither, but summoned the inventor into court to defend his rights. The trial was held in the Court of King's Bench in July, 1781. It went against Arkwright because "the descriptions of the machinery in the specifications were obscure and indistinct." There was no attempt to show that he was not the rightful inventor. The case was an undisguised attack upon his acknowledged rights in the hope that some technicality would cause him to lose. Four years later the judgment was reversed, but in a third trial the opposition brought forward three witnesses, one of whom swore that he had invented the roller spinning-machine seventeen years before. Arkwright was unprepared for such dishonorable methods, and, because the court would grant no extension of time, the case was finally lost. But the king knighted him, for he was the acknowledged inventor, and his prosperity continued unabated.

Arkwright was a picturesque figure even for those times. His biographer says:

"He commonly labored in his multitudinous concerns from five o'clock in the morning till nine at night; and when considerably more than fifty years of

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age, feeling that the defects of his education placed him under great difficulty and inconvenience in conducting his correspondence, and in the general management of his business, he encroached upon his sleep, in order to gain an hour each day to learn English grammar, and another hour to improve his writing and orthography. He was impatient of whatever interfered with his favorite pursuits; and the fact is too strikingly characteristic not to be mentioned, that he separated from his wife not many years after his marriage, because she, convinced that he would starve his family by scheming when he should have been shaving, broke some of his experimental models of machinery. Arkwright was a severe economist of time; and, that he might not waste a moment, he generally traveled with four horses, and at a very rapid speed. His concerns in Derbyshire, Lancashire, and Scotland, were so extensive and numerous as to show at once his astonishing power of transacting business, and his all-grasping spirit. . . . So unbounded was his confidence in the success of his machinery, and in the national wealth to be produced by it, that he would make light of discussions on taxation, and say that *he* would pay the national debt."

Arkwright amassed an estate of about a half million dollars, which was large for those times. He came to be regarded as a personage of importance throughout the kingdom. Since his death in 1792 there has never been the slightest question as to the tremendous contribution which he made toward the revolution in the textile industry.

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Crompton — Kay — Cartwright

Although the inventions of Hargreaves and Arkwright had taken the textile industry a long way toward the elimination of hand labor, much more needed to be done. There were undeniable defects in the inventions of both these men. But the decision of the courts in Arkwright's case, unjust as it was, opened the way for the work of other inventors without fear of infringement and possible prosecution.

Samuel Crompton was one of the first to improve upon these early devices. His work was equally as important as that of his two predecessors. Crompton was born at Bolton, Lancashire, in 1753, the son of poor parents, and was compelled from childhood to earn his living by spinning. In this work he employed a Hargreaves spinning-jenny and also became acquainted with Arkwright's spinning-frame. His alert brain was quick to discover alike the defects and the good points of each type of machine. Gradually there crept into his mind the determination to devise a machine which should eliminate the one and retain the other. Acquainted with the fates that had overtaken his two earlier rivals, Crompton did his experimenting in secret, actually concealing the parts of his machine in the walls and ceiling of his house when they were not in use. The result was the "spinning-mule," a machine which employed the rollers of Arkwright's frame to draw out the thread, and the spindles of Hargreaves' jenny to give the twist. This sounds simple enough, but it was a most difficult task to com-

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bine these principles into a practical working device. Yet Crompton succeeded in accomplishing what had proved to be a totally baffling problem for Hargreaves and Arkwright.

Gradually the public began to discover that Crompton was putting upon the market a superior quality of thread. They surmised existence of some new device and were not satisfied until by fair means or foul they had learned the secret. Too poor to take out a patent, Crompton was unwise enough to allow certain unscrupulous manufacturers to use his machine, upon the promise that they would pay him liberally later on. They did not keep their word; all that the inventor ever received was sixty pounds. This was small reward for a device that increased enormously the capacity of the textile mills of England and greatly cheapened the cost of production.

Crompton's spinning-mule was at first operated by hand. Each machine required the constant attention of one operator. But water-power was soon substituted, and by 1825 Richard Roberts had placed it upon an automatic basis. Both the spinning-frame of Arkwright and Crompton's mule are still in use. Improved as they have been by a host of inventors, they form the basis of the complicated spinning machinery of the present day.

In the early days of the eighteenth century the art of spinning had advanced more rapidly than that of weaving. The weavers could not keep ahead of the spinners, and some device for weaving cloth more quickly was badly needed. The industry did not have

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long to wait, for John Kay, in 1738, invented the "flying-shuttle," a device which did for weaving what Hargreaves' jenny did for spinning a generation later. It doubled and quadrupled the output of the weaver.

In the old method of weaving, two men stood beside the loom. One of them threw the shuttle carrying the weft thread across the warp threads to the second man who caught it in his hand. Kay's flying-shuttle loom caught the shuttle by a mechanical device and enabled one man to operate the loom. But Kay was looked upon as an enemy of labor, and the workingmen rose up against him, smashed his machines, and drove him from the county. Although his device enabled the weavers quickly to outdistance the spinners, and was soon adopted throughout the kingdom, the inventor died without receiving any financial reward. Robert Kay, a son, invented the "drop-box" which made possible the weaving of checkered effects as easily as single colors.

One more invention was required to put the weaving industry on the highway to its wonderful development of modern times — the power-loom. Many unsuccessful attempts had been made in this direction, but not until Dr. Edmund Cartwright, an English clergyman, took up the problem was it solved. Cartwright knew nothing of the textile industry. He had never even seen a weaver or a loom at work. Up to forty years of age he had followed the quiet life of a scholar. Then a chance conversation turned his attention to the field of mechanics. As a result the rest of his long life was devoted to invention.

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We shall let Cartwright himself tell how he happened to invent the power-loom. In a letter to a friend he wrote,

"Happening to be in Matlock in the summer of 1784, I fell in company with some gentlemen of Manchester, when the conversation turned on Arkwright's spinning-machinery. One of the company observed that as soon as Arkwright's patent expired so many mills would be erected, and so much cotton spun, that hands never could be found to weave it. To this observation I replied that Arkwright must then set his wits to work to invent a weaving mill. This brought on a conversation on the subject, in which the Manchester gentlemen unanimously agreed that the thing was impracticable; and in defense of this opinion they adduced arguments which I certainly was incompetent to answer, or even to comprehend, being totally ignorant of the subject, having never at that time seen a person weave. I controverted, however, the impracticality of the thing, by remarking that there had lately been exhibited in London an automaton figure which played chess. 'Now you will not assert, gentlemen,' said I, 'that it is more difficult to construct a machine that shall weave, than one which shall make all the variety of moves which are required in that complicated game.' Some little time afterward a particular circumstance recalling this conversation to my mind it struck me that, as in plain weaving, according to the conception I then had of the business, there could only be three movements, which were to follow each other in succession, there would be little difficulty

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in producing and repeating them. Full of these ideas, I immediately employed a carpenter and smith to carry them into effect. As soon as the machines were finished, I got a weaver to put in the warp, which was of such material as sail-cloth is made of. To my great delight, a piece of cloth, such as it was, was the product."

Up to this point Cartwright had never observed the process of weaving as it was carried on at that time. This first loom, although far from perfect, was the product of his own originality. He then entered the mills and studied the machines in operation. He says, "You will guess my astonishment when I compared their easy modes of operation with mine. Availing myself, however, of what I then saw, I made a loom, in its general principles nearly as they are now made. But it was not till the year 1787 that I completed my invention, when I took out my last weaving-patent, August 1st, of that year."

But the experiences of Cartwright in getting his loom introduced was similar to those which had greeted his predecessors. The workingmen fought it, and the manufacturers pirated his patent rights. A factory in which he had succeeded in putting into operation five hundred looms was destroyed by an incendiary fire. Later Parliament voted him ten thousand pounds, but this sum did not more than reimburse him for his expense in perfecting the invention and in fighting his legal battles. His only reward has been the honor accorded by history.

Cartwright described his first machine, in his patent

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specifications, as follows, "The shuttle, instead of being thrown by hand, is thrown either by a spring, the vibration of a pendulum, the stroke of a hammer, or by the application of one of the mechanical powers, according to the nature of the work and the distance the shuttle is required to be thrown, and, lastly, the web winds up gradually as it is woven." In addition the loom provided complete mechanism for making cloth, and was operated by a crank and handle. Going on from this crude beginning, Cartwright designed weaving machinery, embodying nearly all the essential devices in the wonderful looms of today. But the industry was not ready for them. Yet his simpler looms were soon introduced throughout Great Britain and added one more impetus to the development of the textile industry.

To the end of his life in 1823, Cartwright continued to invent. He devised many machines for use in agriculture and manufacturing. Another invention which he contributed to the textile industry was a device for carding wool by machinery. But the outcry against this contrivance was like that against all the rest. In a suit to defend his patent rights he won the verdict and a judgment of one thousand pounds.

Now, after a lapse of a century, we may look back to Dr. Cartwright as a pioneer in the manufacture of textiles.

Eli Whitney

Now the scene shifts to America. Textile machinery is useless without sufficient fiber to spin and weave.

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Until nearly the close of the eighteenth century, most of England's supply of cotton had come from India. But in 1793 an invention appeared which was destined to develop the cotton industry of the South until sixty per cent of the world's total supply should be raised south of the Ohio River and north of the Rio Grande. It was the cotton gin, invented by Eli Whitney, the son of a New England farmer.

Whitney was born at Westboro, Massachusetts, in December of 1765. As a lad, he displayed a remarkable mechanical bent and was more interested in the use of tools than he was in school. At the age of twelve, he made a fiddle and learned so much about this instrument that fiddles were frequently brought to him for repair. The story is told that, feigning sickness one Sunday morning, he remained home from church in order to take apart and put together his father's watch, which he did without mishap to the costly timepiece. During the latter years of the Revolutionary War, he carried on a profitable business in the manufacture of nails. To his shop soon came all sorts of repair work and he earned the reputation of being the best mechanic in town. When, with the close of the war, the making of nails was no longer profitable, he turned his mechanical ingenuity to account by making hat-pins for ladies' bonnets and walking-sticks for men.

Because of his love for working with tools, Whitney refused his father's proposal to send him to college, and not until he was nineteen did he repent of this decision. By teaching, and through a loan made to

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him by his father, he obtained the money necessary to defray his college expenses and entered Yale at the age of twenty-three. Often, during his college course, he repaired broken pieces of apparatus. A carpenter, from whose shop he had borrowed tools, remarked one day, "There was one good mechanic spoiled when you went to college."

Upon graduation from Yale, Whitney started for South Carolina to take a position as tutor in the home of a southern planter. But smallpox delayed his voyage from New York, and he arrived in the South only to find the position already filled. On the voyage, however, he had become acquainted with the widow of General Nathaniel Greene, and the manager of her Georgia estate, Phineas Miller, who was also a Yale man. At their invitation Whitney took up his home on the Greene estate and began the study of law. This circumstance proved to be the turning point in his career.

The story has often been told of how one evening Whitney observed that the tambour frame, upon which his hostess was embroidering, tore the delicate silk of her pattern, and how the next day, to her delight, he made for her a much better frame. This incident established his mechanical ability in the eyes of Mrs. Greene. When, shortly after, she heard a number of southern planters discussing the difficult problem of separating the seeds from cotton-fiber, she told them of Whitney's inventive genius and suggested that he devise a machine for this purpose. At that time he had never even seen cotton. But his mechanical instinct

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prevailed, and he made a trip to Savannah to obtain a quantity of raw cotton for purposes of experimentation. Whitney had no money and no tools. But Phineas Miller supplied the money, and Whitney made the tools. Turning a room of the Greene mansion into a shop, he was soon at work.

In a short time he had a remarkable machine. As described by Henry Smith Williams, it "consisted of circular saws set close together on an axle, arranged so that they played between narrow slots in a comb-like piece of metal. As the cotton was fed to these saws, the fibers were seized and drawn down through the slots, which were too small to allow the passage of the clinging seeds. A series of revolving brushes on the opposite side removed the cotton fibers, delivering them as fleecy cotton-down free from seeds, while the seeds rolled away into a receptacle made to receive them." Up to this time it had required a swift worker a whole day to separate the seeds from a single pound of cotton. But with Whitney's gin the output was increased to one hundred pounds.

No wonder the planters came from far and near to see this machine at work! But one dark night some unscrupulous men broke into Whitney's shop and carried off his gin. Their purpose was not to demolish his invention but to steal his idea. Everyone foresaw the influence which this device would have upon the cotton industry of the South, but they did not wish to let Whitney reap the reward of his ingenuity. Immediately Whitney returned to Connecticut, where he constructed a model and obtained a patent from the

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Federal Government. There he also built a factory and began the manufacture of his gins. But the factory was soon burned, and the southern planters were freely pirating his invention. Whitney fought a long and discouraging battle for his rights. In the end he was granted, by the legislatures of three southern states, something less than one hundred thousand dollars, for his rights, but this little more than covered the expenses of litigation and the work of invention.

Not only did the cotton gin have a profound effect upon the textile industry, but it also revolutionized the life of the South and riveted slavery upon that section of the country until the black men were freed by Civil War. At that time, so dependent had English textile mills become upon American cotton, that the working people of England, thrown out of employment for lack of fiber, bitterly opposed the North in the War of the Rebellion. But it is safe to say that without Whitney's invention, cotton would never have become the principal staple of the South, nor this country the chief source of the world's supply. In the very first year of the invention's adoption the cotton crop increased to five million pounds, and in the year of Whitney's death, 1825, the value of the cotton exported from this country exceeded that of all other exports, by more than six million dollars. In 1921 the output was four billion, one hundred and seventy million pounds. Seldom has any invention had a more important influence upon the industrial life and political system of a great people than Whitney's cotton gin upon those of the United States.

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CHAPTER V

TWO PIONEERS OF MODERN ASTRONOMY

Sir William Herschel

"I have looked farther into space than ever human being did before me. I have observed stars of which the light takes *two millions* of years to travel to this globe." So spoke Sir William Herschel, the son of humble Hanoverian parents who became an English subject by adoption and rose to knighthood because of his important astronomical discoveries. But what a stupendous statement this royal astronomer made, and yet quite possibly true. Light traveling at the prodigious speed of one hundred and eighty-six thousand miles per second may require two millions of years to come to us from a comparatively nearby portion of our universe! And Sir William estimated that this starlight travels a distance of "at least eleven and three-fourths millions of millions of millions of miles." To comprehend a universe so vast bewilders thought and staggers the imagination. Even the light from our nearest stellar neighbor he estimated to be three and a half light-years away, which means that if this star should go out tonight it would continue to shine on at the same point in the heavens and with the same brilliancy for three and a half years to come. Should the orbit of the earth, which is one hundred and eighty-six

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million miles across, be represented by a lady's finger ring, this nearest fixed star on that scale would be a mile and a half distant. Such is the universe to which Sir William Herschel was the first to introduce us. Copernicus, Kepler, Galileo, and Newton had given us the solar system, but they did not unveil the vastness of the stellar world.

The fourth in a family of ten children, William Herschel was born in Hanover, Germany, in 1732. His father taught him music and he learned to play on a number of instruments. At nineteen he abandoned his native land and sought his fortune in England. Three years were passed in poverty and hardship, but all the while he studied music and soon rose to considerable prominence in his chosen profession. So popular did he become that pupils flocked to him and prosperity came in abundance. In his eagerness to gain a mastery of the theory of music, Herschel began the study of mathematics. This new branch of knowledge fascinated him. It unfolded a vast new field for his active brain. The pursuit of mathematics soon inspired him with an ardent desire to explore the heavens. Astronomy gradually absorbed every spare moment that he could steal from his professional duties. In the brief intervals between the numbers played by the orchestra which he directed, Herschel would rush from the concert hall to study the stars. With a small telescope loaned to him by a friend, he began his investigations of the heavens.

But the small reflecting telescope first used was inadequate for his purpose. The refracting telescope

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employing large lenses had not then been brought to any degree of perfection. Herschel did not have the means to buy a large instrument, and therefore his only hope of being able to gratify this ambition to penetrate beyond the bounds of the comparatively little universe of his predecessors lay in constructing a telescope of his own. He turned his home into a workshop and began to cast and figure a mirror which should gather more light from the stars and bring it to focus in an image which he might observe with a magnifying eyepiece. He devised an alloy consisting of a mixture of two parts of copper and one of tin. This gave a hard material capable of taking a polish almost equal to that of silver. So proficient did he become in this most exacting art that he was called upon to build larger and larger telescopes for many in his own and other lands. In a few years his instruments had become famous and from their sale he amassed a considerable fortune.

From his early home in Germany Herschel brought his sister Caroline, who was passionately devoted to her brilliant brother. She became his constant companion and co-worker for many years. Evening after evening, together they watched the stars through the telescope, frequently remaining out all night. Caroline cheered her brother in these long hours, with her presence, and recorded his observations. Often the ink froze in her pen, so cold was the night. History scarcely affords an example of greater devotion than was exhibited by Caroline Herschel, who also became an astronomer almost as famous as her brother. She was at once his

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housekeeper and professional assistant. In the difficult work of fashioning a telescope mirror, it is at times necessary for the workman to remain with his hand on the figuring tools for hours at a time. In these tedious periods Caroline was accustomed to sit at her brother's side reading to him and at times feeding him from a spoon as he worked. She performed his mathematical calculations and copied the numerous papers which he prepared for scientific societies. Without the never failing aid of his faithful sister, Herschel might have remained unknown to the scientific world.

But years passed and Herschel had reached the half-century mark before these patient observers made a discovery of importance. He had conceived the idea of examining every star above a certain magnitude. Star after star was brought into view by his telescope, the largest and most powerful ever built up to that time. Still there was no success. Only a brilliant point of light greeted his gaze, for even the largest telescope is unable to magnify a star, at such an infinite distance is it from us. Telescopes only serve to gather more light and thus make the stars appear brighter. Herschel had examined hundreds and even thousands of stars but each one had been dismissed without comment. They all looked alike. Then, one night in March 1781, a new world flashed into view. In that moment the years of fruitless observation vanished in the joy of discovery. Upon that memorable night he had turned his telescope upon the stars in the constellation of Gemini. Suddenly his trained eye observed a star that arrested his attention. He

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called for a glass of higher magnifying power, and to his extreme delight, instead of the usual brilliant point, he beheld a shining disc of measurable size and totally different from the myriad of stars about it. As he watched it from night to night, its position shifted among the stars. There could no longer be any doubt. A new planet had been discovered. Another member had been added to the family of the solar system.

The new celestial body was named Uranus. From the days of the Chaldean shepherds only five planets had been known — Jupiter, Saturn, Mercury, Venus, and Mars. This achievement of Herschel's is the first instance on record of the discovery of a planet. Saturn had hitherto been regarded as the outermost member of the solar system, but here was a planet whose majestic swing about the sun requires for its completion a period of eighty-four years. Immediately Herschel was lifted into fame. King George the Third invited this "silent watcher of the night" to visit the royal palace and to bring his telescope with him. His Majesty was so delighted with what he saw that he made Herschel the astronomer royal, and granted him a pension and funds for the erection of still larger telescopes. Later he was knighted. And the king did not forget the discoverer's sister, for he granted her a pension too.

Relieved now of the necessity of earning his livelihood, Herschel devoted his remaining years to his beloved pastime. The discovery of double stars, nebulae, star clusters, and comets in the utmost profusion were the results of his nightly vigils. But

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nothing else that he ever discovered was equal to his famous discovery of the planet Uranus. In 1822 he died, but he left a son Sir John Herschel, whose renown as an astronomer was second only to that of his father. His sister Caroline reached the advanced age of ninety-eight, and before her death received the merited recognition of kings and scientific men.

Pierre Simon de Laplace

The name of the distinguished French mathematician Pierre Simon de Laplace will forever be associated with the Nebular Hypothesis, which he put forth to explain the origin of our solar system. His last words were, "What we know is but little, what we do not know is immense." It was to satisfy in some small degree mankind's insatiable thirst for knowledge of our universe that he devoted his life. He was born at Honfleur, France, in 1749, the son of a farmer. His father was able to give him a good education, and he early displayed a bent for mathematics. At eighteen he had become a teacher of his favorite subject and a little later brought himself to the attention of D'Alembert, the most profound mathematician of the French capital. This powerful friend at court soon obtained for him a professorship in mathematics at the Military School in Paris.

At twenty-three Laplace began to publish that long series of brilliant memoirs on mathematical subjects which were to stamp him as one of the leading philosophers of Europe. One by one he attacked and

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successfully solved the difficult problems in the application of Newton's theory of gravitation to the explanation of our solar system. Availing himself of a branch of mathematics founded by Newton and known as the infinitesimal calculus, he was able to account for the movements of the heavenly bodies. He brought the disturbances resulting from the influence of one planet upon another, under the sway of this far-reaching law. In his great work entitled "Celestial Mechanics" he reduced the heavens to a system of crystallized mathematics. He marshals the motions of planets, satellites, and comets as a skillful general orders the movements of the various units of his army. But its pages are so packed with mathematical formulae and equations that only the few can understand its contents. Yet it will always remain a classic in its field.

But Laplace did prepare one treatise that all the world has been able to understand. It is his "System of the World," in which he set forth his celebrated Nebular Hypothesis. Upon this theory his chief claim to lasting recognition rests. In his observation of the heavens, a number of significant facts had challenged his attention. He had noted that all of the planets revolve in the same direction about the sun, which is also in the same direction as their respective rotations, as well as that of the sun itself. In addition he observed that all the satellites known at that time revolved about their planets and rotated upon their axes in this same direction. To the mathematical mind of Laplace this could not simply *happen* to be so.

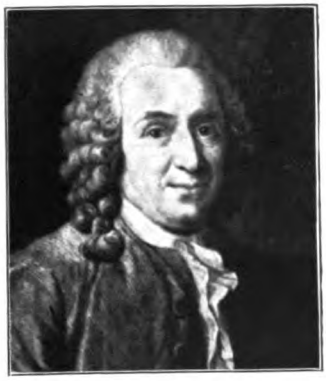
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JENNER



MORTON



LINNAEUS



LAMARCK



CUVIER



HUMBOLDT

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MME CURIE



HERSCHEL



LAPLACE

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There must be some reason. He demonstrated that such a striking coincidence could occur by mere chance only once in five hundred million times. But what was the cause? With his mathematical ability and profound knowledge of the heavens, Laplace set for himself the solution of this problem. His idea was to devise an original set of conditions of which our solar system must be the necessary consequence.

Laplace conceived the material of our solar system as existing in the remote past — billions and billions of years ago — as a thin vaporous firemist, or nebula. He thought of it as a vast cloud of highly heated, incandescent matter stretching for immense distances beyond the present limits of the system. What is the source of this heat and luminosity no one can say. Thousands of these nebulae are revealed by our telescopes. They seem to be vast whirlpools of cosmic motion, other suns and worlds in the process of formation, even as Laplace conceived our solar system to have been formed. The light, tenuous particles of firemist he assumed to be in motion, doubtless rotating upon their axes and revolving together about a common center. As time passed — billions of years — this mass would gradually cool down and slowly coalesce into a huge central mass, surrounded by a vast area of outlying uncondensed vapors. In these uncondensed vapors other small centers of attraction would be set up, and about them in turn after countless ages still smaller centers would appear. From the initial motions of the glowing mass there would inevitably be resultant motions of rotation and revolution. Thus

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did Laplace provide for the birth of a solar system consisting of sun, planets, and satellites. Although there are difficulties in the way of a complete acceptance of this view, it is conceivable that a solar system could be evolved in accordance with this plan. It answers every condition of a genuine working hypothesis and has been of immense importance in the clarification of astronomical fact and theory. The spiral nebulae which dot the heavens in such abundance offer plausible evidence of the correctness of the view. Whether in the light of more recent knowledge this theory will ultimately prevails is still a problem of the future. Certain it is, however, that this conception of the origin of our solar family will forever distinguish its author as one of the boldest thinkers of any age. Previously to Laplace Immanuel Kant had put forth a similar hypothesis, but he was unable to give rigid mathematical demonstration of its plausibility.

Laplace was honored with political preferment by Napoleon and made a Marquis by Louis XVIII. But his chief service was to the cause of science. He died in his seventy-eighth year.

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CHAPTER VI

TWO NOBLEMEN OF SCIENCE

The beginning of the last century presented to the would-be discoverer of Nature's secrets a veritable paradise of possibilities. The great discoveries of chemistry and physics were still to be made. The mastery of those forces which have enabled men to unlock the resources of the earth had not yet come. Two-thirds of the chemical elements were unknown. The laws of chemical action were scarcely problems. Electricity was a toddling infant. Astronomy was the only science stretching backward to antiquity. Yet the old order was passing. The foundations of the new had been laid. Unrest was sweeping the world. The atmosphere of every European capital tingled with suppressed interest in all things scientific. The new force of voltaic electricity had captured the popular imagination, and new wonders were eagerly anticipated. At this happy moment appeared two young scientists, whom we should now designate as home-laboratory workers. They were Humphry Davy and Michael Faraday.

Sir Humphry Davy

Imagine yourself at the entrance to the Royal Institution of London almost a century and a quarter ago. About you are the liveried footmen and the carriages

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of the aristocracy. Their richly attired occupants, mingling with persons from the humbler walks of life, are entering the spacious hall and mounting the stairway to the lecture room. You follow, and are soon seated on a cushioned bench before a demonstration desk, upon which is displayed an imposing array of chemical and physical apparatus. Presently a hush falls upon the audience. Interest is manifest on every side. You look up and observe upon the platform the attractive figure of a young man accurately dressed in the prevailing fashion. His genial smile and charming manner win your confidence at a glance. He begins to speak and the rich, musical tones of his voice, together with the earnestness of his delivery, command your attention. He is presenting the results of recent discoveries, which he has made in the laboratory of the Institution. His assistant steps forward. The master begins to demonstrate with the apparatus before him. Every eye follows his movements. His audience is fascinated. Under his skillful direction every experiment goes without a hitch. The expectancy of his hearers is not disappointed. Frequent applause tells him of their appreciative interest. So clear is his discourse, so copiously illustrated, that all may understand. For two hours you are spellbound. Then the lecture ends, and the audience, overflowing with enthusiasm, makes its way to the street and the waiting carriages. You have listened to Humphry Davy, the youthful Professor of Chemistry at the Royal Institution, and the most popular man in London.

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Born in 1778, in Penzance, Cornwall, England, the son of a woodcarver, there was nothing unusual in his boyhood. At sixteen his father died and young Davy was apprenticed to an apothecary and surgeon of his native town. A little later a copy of Lavoisier's "Elementary Chemistry" fell into his hands, and from it he acquired his first fondness for the subject which in a few years was to make him famous. He began to experiment for himself, much to the dismay of his elders, who feared that his frequent explosions would "blow them all into the air."

About this time Dr. Thomas Beddoes had established the "Pneumatic Institution" at Bristol for the purpose of testing the physiological properties and curative effects of all the gases known at that time. Having learned of Davy's interest in chemistry, Dr. Beddoes invited the young scientist to take charge of the investigations. It is an excellent indication of the state of science at that time that a novice with no training whatever should be chosen for so responsible a position. Today we should require a man with a university training and a number of degrees. But science was then in the making, and such men were not to be found.

Davy set out for Bristol in high spirits. Always of a poetic temperament, his imagination took full play, as he sat in the stage coach which he felt certain was bearing him to fame and fortune. And true to that vision the events of his life proved.

Davy had scarcely entered upon his new duties when he discovered the anaesthetic properties of

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nitrous oxide, now so widely used in dental surgery. No wonder this period has been called the paradise of scientific discovery. Here was an untutored country lad with no experience in laboratory work who blundered onto one of the great discoveries in the history of medical and chemical science. Because the breathing of this gas intoxicated Davy and made him dance about the room like a madman, it has ever since been called "laughing gas." Its use soon became a popular fad throughout the kingdom, and the fame of Davy and his Institution was on every tongue.

But his experiences in recklessly breathing gases, the poisonous properties of which were wholly unknown, nearly cost him his life. After breathing water gas, which contains the deadly carbon monoxide, he was with difficulty brought back to consciousness. These dangers were happily ended by his accepting an invitation to become Assistant Professor of Chemistry and Director of the Laboratory of the newly established Royal Institution in London. This institution, founded originally for the betterment of the condition of the poor, by Count Rumford, an American Royalist and soldier of fortune, soon became the most renowned center for scientific discovery to be found in the capitals of Europe. This fame was due, as we shall see, to the brilliant researches of Davy.

Davy took up his duties in March 1801 and soon advanced to a full professorship, a position which he held until 1813 and in an honorary capacity until his death in 1829. His first important lecture, delivered in January of the following year, made a remarkable

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impression. Davy was a real orator, and his gifts for investing even the driest subjects with interest were little short of marvelous. His lectures became the sensation of the hour. The aristocracy flocked to Albemarle Street to hear him. The king mentioned him with favor. He was lionized by the polite society of London. Invitations to dinner and social functions poured in upon him. It seems strange that this sudden wealth of popularity did not ruin him. But while Davy retained to his dying day the power to hold the public fancy, it did not prevent him from carrying out some of the most noteworthy researches to be found in the history of chemistry. Indeed, it was these very researches that gave him the means to build his popularity. As a condition of his position, the results of his work were given to the public at intervals in popular lectures.

After going to London his first important work was to establish for all time the true chemical nature of the electrolysis of water. But the discovery for which Davy will forever be remembered is that of the alkali metals, potassium and sodium. In common with Lavoisier, Davy believed that the two substances known as potash and soda were not elements, but compounds of oxygen and hitherto unknown metals. Here was a problem fit to challenge the powers of the most skillful analyst. Could anything be more fascinating to a youthful chemist than such a problem, with the best equipped laboratory of his time in which to solve it? Such was the fortunate position of Davy. Employing a powerful voltaic battery, he placed upon

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a disc of platinum a piece of pure potash and connected the substance by a platinum wire to the positive pole. The platinum disc he joined to the negative pole. Presently a vigorous action was set up. The potash began to fuse, and shining globules of molten metal resembling quicksilver appeared on the platinum disc. Davy was so overcome with joy at sight of the new metal that he could not contain himself but danced about the room from sheer delight. In like manner he discovered sodium, and shortly after decomposed the oxides of barium, calcium, strontium, and magnesium. The electrolytic process which Davy here employed is the basis of many modern industries. Had he done nothing else, he would be entitled to enduring fame. A little later, with a powerful battery of two thousand cells, which had been provided by popular subscription, Davy astonished his audiences by producing the first electric arc light in history.

The poisonous gas chlorine had long been thought to be a compound of some unknown element and oxygen. Davy proved it to be an element, and first explained its bleaching properties. Taking the newly discovered element iodine, he determined its properties as we know them today. Assisted by Faraday, he did pioneer work in the liquefaction of gases. He experimented with the poisonous hydrofluoric acid and the explosive nitrogen chloride. He was called upon by the directors of the Institution to do original work on a great variety of subjects, particularly in the field of agricultural chemistry. His book on this subject remained the most important work of its kind until

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the time of Liebig. The triumph of his later career was the invention of his safety lamp, which has saved thousands of lives in the coal mines of England and America.

For his services in the cause of science, he was knighted by his king and later made a baronet. Stricken with paralysis, while yet in the prime of life, his physical powers gradually withered away. He died when only fifty-one.

Michael Faraday

It has been said that in nothing did Sir Humphry Davy render more praiseworthy service than in the training of his assistant, Michael Faraday. Faraday, the son of poor parents, was a newsboy and a bookbinder's apprentice, who, through the kindness of a friend, enjoyed the privilege of attending a course of lectures given by Davy at the Royal Institution. Faraday was then nearly twenty-two and had found the life of a tradesman distasteful. He had already dabbled in science and these lectures, delivered with all the eloquence for which Davy was renowned, crystallized the longing of his young soul to become a scientist. While listening to the lectures, he had taken full notes, and had made drawings of the apparatus used in the experiments. These he sent to Davy with a letter telling of his ardent desires, and requesting his appointment as assistant in the Royal Institution. Davy made courteous acknowledgement of the note and promised an interview. Imagine

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Faraday's surprise and joy when a few weeks later a coach drew up at his door and a liveried footman bore a message from Davy, offering him the coveted position. Faraday accepted with alacrity and was soon established in the two rooms assigned him at the top of the Institution. Here he was destined to labor in the cause of science and the interests of his fellowmen for more than fifty years, and to become the most illustrious scientist of his time, even as Davy had been before him.

In his evenings Faraday studied to gain the education which would be fundamental to his future advancement. During the day he assisted Davy in researches and set up the apparatus for the lectures of the Institution. Can you imagine a more speedy and complete realization of one's heart's desires? As by the waving of a magician's wand, here was the young apprentice assisting the master and having at his disposal the best equipped laboratory of Europe. Such was the fortune of those favored sons whose privilege it was to work in the heyday of scientific discovery.

Faraday's first work was to help in the preparation of the explosive nitrogen chloride. In one of the numerous explosions that resulted he received thirteen pieces of glass in his eye. Not a pleasant introduction, but it did not in the slightest degree dampen his enthusiasm. In the autumn of that year, 1813, Faraday accompanied Sir Humphry and Lady Davy on a trip through the principal cities of Europe. The fame of Davy had gone before him. Everywhere they were

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received with the utmost deference. The laboratories of rival scientists were thrown open to him, and Faraday assisted in his experiments. Faraday thus met the leading men of science of that day and formed friendships that were to last throughout his life.

Upon their return to England, Faraday resumed his duties as laboratory assistant and above all perfected himself in the knowledge and practice of chemistry. In 1816 he began to lecture on chemistry before the City Philosophical Society and there gained the experience which was to make him the most polished lecturer of his time. Under the direction of Davy, he carried out experiments that led to the invention of the safety lamp. In heating the solid compound of chlorine and water in a bent glass tube, Faraday accidently obtained liquid chlorine. Later he succeeded in liquefying all of the known gases except six, which, when means for obtaining greater degrees of cold had been perfected toward the close of the century, were liquefied in that same laboratory. In 1825 he discovered benzene from the distillation of coal tar. This first sample of a compound of such tremendous importance to modern industry is still preserved in the British Museum. In 1823 Faraday had been elected a Fellow in the Royal Society, and two years later he became Director of the Royal Institution.

As his skill in experimental science became known, his services were in great demand by the manufacturers of London and other cities. With this demand came the turning point in Faraday's career. He had

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to choose between the lucrative fees of professional work and the cause of science with its meager stipend. Had wealth been his object, it was within his grasp. Huxley estimates that, had Faraday applied his great talents to commercial work, he might easily have amassed a fortune of three quarters of a million dollars. But the world would have been immeasurably poorer. To the glory of Faraday, he did not hesitate. He resolutely turned his back upon private gain. His one passion was to add to the sum of human knowledge. No other investigator ever added more. But his rôle was always that of a discoverer. Whenever a new discovery had been made, he left its commercial development to other men and turned with renewed enthusiasm to fresh fields of research. In this day of intense rivalry it is good to contemplate such utter forgetfulness of self and such complete devotion to truth for truth's sake.

But it was in the field of experimental electricity that Faraday did his most important work. In 1819 Hans Christian Oersted, a Danish physicist, had made the important discovery that a current-bearing conductor possesses a magnetic field. In the following year Ampère of France had found that a coil of wire, through which a current flows, has all the properties of a magnet. In 1824 Sturgeon made the first electromagnet, and Joseph Henry in this country was beginning his pioneer work in that field.

Faraday repeated all the experiments in this newly discovered field and added many more of his own. In one of his note books, we read: "*Change magnetism into electricity.*" He experimented patiently, but with

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no success. Yet it seemed clear to him that if a current-bearing conductor possesses a magnetic field it should in some way be possible to induce an electric current by means of a magnetic field. After ten years of persistent knocking at the door of truth, the answer came. In 1831, in a series of never-to-be-forgotten experiments, Faraday in quick succession discovered the laws of induced currents, and in so doing laid the foundations for the unparalleled triumphs of modern electricity. He made the fundamental discovery that whenever lines of magnetic force are made to cut across a conductor, or a conductor is made to cut across lines of force, a current is induced in the conductor. In this basic principle lay the invention of the dynamo, the electric motor, the induction coil and transformer, the x-ray, and a host of revolutionizing applications of this mysterious form of energy. Without this discovery electricity would still be the plaything of science. Immediately following this, Faraday in a series of researches worked out the laws of electrochemical action and invented the first accurate electric measuring instrument.

With these triumphs Faraday passed the zenith of his powers. He continued to experiment and lecture for many years, but a physical breakdown in 1841, from which he never fully recovered, hampered him in his work. He was pensioned by his government and honored by the universities and learned societies of every land. Quiet and unassuming, of childlike gentleness and simplicity, Faraday is best described in the epitaph bestowed upon him by his friend, John Tyndall, "Just and faithful knight of God."

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CHAPTER VII

FOUR GREAT NATURALISTS

Carl Linnaeus

Deriving his name, according to tradition, from a tall linden tree, which grew in the garden of his ancestral Swedish home, Carl Linnaeus from early childhood displayed a remarkable fondness for trees and flowers. Indeed, all Nature fascinated him. Plants, animals, rocks were his chief sources of delight. His father was a Lutheran clergyman and had intended that Carl should follow the same profession. But the beauty of his garden, blooming with four hundred species of flowers, made a lasting impression upon the mind of young Linnaeus. Even at four years of age the charm of living things had cast a spell about him. When at the age of ten he was sent to a school at Wexio, his love for the flowers and insects that abound in open fields and shady nooks led him to neglect his work. His tutors complained to his father, and Linnaeus confessed that he was enraptured with botany. Even at the expense of grieving his father, he had to tell him that he had no liking for the ministry. The elder Linnaeus, unable to appreciate the boy's longing for the life of a naturalist, decided to apprentice him to a shoemaker. But the scientific world may ever be grateful that Dr. Rothmann, a

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physician of the family's acquaintance, rescued the lad from so unprofitable a career. Sympathizing with the boy's irrepressible desire to become a botanist, this good doctor took him into his own household and taught him both medicine and natural science.

In 1727, when he was twenty years of age, Linnaeus enrolled at the University of Lund, where he studied some medicine and more botany. Again he was fortunate in his associations, for Professor Stoboeus, the lecturer in botany, received him as one of his own family and granted him the freedom of his museum, containing rare collections of minerals, shells, and dried plants, as well as access to his large library. This was paradise for the young naturalist. Immediately he began to scour the countryside for new plants, and started an herbarium of his own. On one of these botanizing trips, he was bitten by a venomous reptile with such serious consequences that he nearly lost his life. Still Linnaeus' love of Nature was too deeply rooted to permit this unfortunate experience to cool his ardor in the slightest degree.

Upon the advice of his staunch friend, Dr. Rothmann, Linnaeus forsook Lund for the University of Upsala. Here, on an allowance of eight pounds a year, he tasted the bitterness of poverty, compelling himself to wear the cast-off clothes of other students, mending his worn-out shoes with paper, and frequently going hungry. His thirst for knowledge was unquenchable. Nature beckoned to him on every side, and once more he was fortunate in finding a friend at court. In exchange for assistance in preparing a work on the

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trees and plants of the Bible, Celsius, the professor of divinity at Upsala, offered him board and room free. Linnaeus accepted gladly, and in the library of his benefactor obtained the idea for his new system of classifying plants, a system that was to revolutionize the science of botany. His principle of classification was based upon the reproductive organs, the stamens and pistils, of plants. He divided all plants into twenty-three classes according to the number and position of the stamens, placing in a twenty-fourth class all of the flowerless plants. Although this system was artificial, and has since been replaced, it represented a tremendous gain. For the first time it afforded a ready means of identifying plants by reference to their natural characters. In that time the physiology of plants was neglected. Even Linnaeus' chief object was to collect, classify, and name the various species. But both in botany and zoology he was a master in the art of describing. When he was twenty-three, Linnaeus was appointed lecturer on botany at Upsala, where he at once became popular both with the students and the college authorities. His broad knowledge of living things and his passionate devotion to science gave a charm and inspiration to his lectures unusual in those days.

In the spring of 1732, Linnaeus went on a naturalizing trip to study the plants and animals of Lapland. It was a difficult undertaking, involving both hardship and peril. Walking, riding, canoeing, he penetrated unknown forests, crossed deep rivers and almost impassable bogs, and climbed rugged mountains, study-

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ing at every step the trees, shrubs, herbs, and animals, as well as the little-known inhabitants of that dreary country. Alone he covered more than four thousand miles and brought back over a hundred previously unknown plants. Even today this journey is ranked as one of the most notable of its kind ever undertaken.

Upon his return to Upsala, Linnaeus found jealous rivals to his well-earned success. Because he did not have a doctor's degree, he was denied the privilege of lecturing further at the university. But rallying about himself an enthusiastic group of loyal students and finding the support of a wealthy patron, he established a small school of his own, in which he lectured on botany and mineralogy. Three years later he forsook his native land for Holland, where he was warmly received by scientific men and shortly after became botanist and physician to a wealthy gentleman named Cliffort, who allowed him a thousand florins a year and free access to his collections of natural specimens from every part of the world. Here he published many of his most important works on botany, and acquired wide repute as one of the distinguished naturalists of Europe. One of Linnaeus' most important contributions to science was his simple system of naming plants and animals. For the cumbersome method of using a number of Latin words, to designate a certain plant or animal, he substituted a scheme requiring but two names. With a few slight changes, this is today the basis of our system of nomenclature.

After traveling extensively on the Continent, Lin-

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naeus returned to Sweden, but, although he had become famous abroad, the learned men of his own country ridiculed his researches. They envied his success and were bitter because he had struck out boldly upon new paths of discovery without due regard for the time-honored theories of the past. He was too much of a revolutionist. For a time he practiced medicine, but soon attracted the notice of the Queen of Sweden and a number of eminent countrymen. Through their influence he was appointed professor of anatomy and physics at Upsala and eventually became lecturer on botany, the position which he coveted most of all. To him came students from the leading countries of Europe and from America. Through them his influence upon the teaching of natural history was carried throughout the educational world, and in this field he will always be ranked as one of the greatest leaders. The numerous Linnaean Societies founded in his honor throughout the world have kept his memory green. He died in 1778, mourned by the entire nation and by scientists everywhere.

Jean Baptiste de Lamarck

To achieve fame, to win recognition as one of the chief founders of a new branch of scientific thought is glory enough for any man, but to do it after one is fifty years of age, and in the face of the bitterest poverty is double glory. Such, however, was the fortune, or fate, of the French botanist and zoologist, Jean Baptiste de Lamarck.

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Lamarck was born in the province of Picardy, France, in 1744, the son of the leading personage of the neighborhood, but a man possessing a large family and an estate too small for his growing needs. The father had intended Jean, his eleventh child, for the Church, but the boy's inclinations were for the army. He had come from a race of soldiers. For generations his ancestors had carried arms, and his eldest brother had been killed in battle. When young Lamarck was sixteen years old his father died, and the parental opposition thus having been withdrawn, he enlisted. France was at that time so sorely pressed for men that even boys made acceptable soldiers. For gallantry in sticking to his post in the face of almost certain death, at the battle of Fissingshausen, Lamarck was made a lieutenant. The young man felt himself securely started on the career of a soldier. But an accident, unfortunate or otherwise, soon dashed his hopes. A practical joke, played upon him by a brother officer, left him scarred for life and unfit for army duty. His recovery required a year of treatment and comparative solitude, in which he passed many hours in quiet reflection. The curious vegetation of the surrounding country aroused his interest and led him to read a book on botany. This chance incident fixed his career. Henceforth the study of botany and Nature in general became the passion of his life.

Like a number of other noted naturalists, Lamarck chose the study of medicine as the profession most closely associated with his life-purpose. But after pursuing this work for four years, earning at the same

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time his means of support, he deliberately forsook medicine that he might devote himself entirely to botany. This was a bold step for a poor young man in the days when the the life of a naturalist offered small hope of financial reward. But in his eagerness to know about plants and flowers and trees, and to increase the world's knowledge of them, he overcame every obstacle. Dissatisfied with the systems of classification of plants devised by Linnaeus and other botanists, Lamarck invented a simpler method. In a short time he was able to produce a treatise on "The Plants of France" which served as a guide for the identification of every plant of his native land and was a real contribution to his chosen science. It attracted the attention of his great contemporary, Buffon, who secured the publication of the work at government expense. At the same time he obtained an appointment in the Academy of Sciences and became traveling tutor to Buffon's son. A monument to his industry and his contribution to science at this time is the botanical section of the "Encyclopédie Methodique," illustrated by plates of the various genera of plants drawn by his own hands.

During the French Revolution Lamarck served as botanist at the *Jardin du Roi* and, although miserably poor, was unmolested by the strife of war. In the quiet pursuit of his favorite subject he added to the world's fund of knowledge and his own renown. Still years passed and he had not found the field in which he was to do his most enduring work. Then, in 1793, the Museum of Natural History was founded in Paris,

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and Lamarck was attached to its faculty. Because no one else would have it, he was assigned to the investigation of worms and insects, a subject previously supposed to be of little importance. Lamarck was not a zoologist. He had never studied animals. He had passed the half century mark and his whole interest had been in another field. But he loved Nature, and to the duties of his new task he set himself with whole-hearted devotion, not dreaming that in this prosaic investigation of lowly forms of life he was to do his most distinguished work and become the founder of a new branch of science.

With contagious enthusiasm and untiring industry Lamarck began to study the vast numbers of animals which had been assigned to him. Their very abundance would have been bewildering to a mind less keen and well trained. Hitherto zoologists had studied chiefly the higher forms of animal life, not realizing that they were approaching the subject from the wrong direction. The infinite variety of these lowly forms and the wonders of their organization became a source of delight to Lamarck. He soon found in zoology a pursuit more fascinating than the field of his first choice. To all of these animals Lamarck was the first to assign the name *invertebrates*. He then began a detailed description of them, and their arrangement into a system of classes, orders, and genera. His guiding principle was the anatomy of the animals. Out of the confusion of previous systems he brought order. He separated the crustaceans, and introduced the new group of spiders. For the first time he described a

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class of worms known as the annelida. He studied the mollusks and named many species of coral. The microscopic infusoria he placed in a class by themselves. The monumental works which he prepared after many years of incessant labor became the standard textbooks in this field.

As a result of his extensive investigations, gradually a new idea crept into Lamarck's mind. Was it not probable, he asked himself, that the higher forms of animal life had evolved from the lower in accordance with some definite law of Nature? His study of the fossil remains of early forms of life gave striking evidence. This idea grew into a settled conviction and shaped the course of his later work. It was the first logical conception of the modern theory of organic evolution, and stamps Lamarck as the forerunner of Darwin. The constantly increasing difficulty which he experienced in drawing sharp lines of distinction between various species of animals gradually convinced him that there are in Nature no real species. Instead, he came to believe that all animals have arisen through slow processes of change from common and lower types of life. He carried the animal life of the earth backward in time to the simplest forms of ancestors. Here was evolution.

But Lamarck did not rest there. He attempted an explanation of this transmutation of species. It seemed to him that the fundamental factors in the process must be use and disuse of organs, and the changing conditions of environment coupled with the hereditary transmission of acquired characters. The

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constant use of an organ developed it, while its disuse caused it to decay. Thus, birds near the seashore would develop long legs from the necessity of wading deeper and deeper in water in search of food. This new character would be inherited by the offspring. By similar methods Lamarck believed that the diversified organs of all creatures had been evolved. On the other hand, if changing conditions of environment, climate, or geographical location caused an organ to fall into disuse, it disappeared. Lamarck, however, did not grasp Darwin's later theory of "natural selection." Darwin, as we shall see, held that changes in organs arise largely by chance and are transmitted through heredity upon the supposition that Nature selects and preserves those characters which are best suited to the environment of the animal, in accordance with his doctrine of the "survival of the fittest." He did believe that acquired characters are transmitted, but he did not stress this point. Whether either or neither of these views represents the correct method no one can say. There can be little doubt, however, of the fact of evolution, and it will be to the everlasting credit of Lamarck that he was the first to place this theory upon a sound basis of scientific observation. But he was ahead of his time. Cuvier, the most influential zoologist of that day, opposed the new views, and Lamarck died without receiving the recognition which he deserved.

Lamarck continued in poverty to the end of his life of eighty-five years. In his latter days his sight failed him, and his physical powers fell away. His

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devoted children, however, never forsook him and amidst all the vicissitudes of fortune he displayed the strongest fortitude. Of a kindly and generous nature, possessing powers of observation and of intellect superior to those of many of his contemporaries, Lamarck left an impress upon the progress of his time which will not be effaced.

Baron de Cuvier

To have such an intimate understanding of the extinct animals of past geologic epochs as to be able to reconstruct a complete skeleton from a single fossil bone is sufficient to rank any man as a naturalist of high order. Such was the ability of Baron de Cuvier, the founder of comparative anatomy.

Cuvier was born in 1769 in Montbeliard, a little town of France, which belonged at that time to the Duke of Würtemberg. His father had been an officer in the Swiss army, who somewhat late in life married a young woman of unusual ability. Cuvier's older brother had died, and his mother cherished her second son with the utmost devotion. Under her wise guidance his extraordinary powers of mind were early developed. Even as a lad he became a prodigious reader. At ten he was placed in a high school where he remained for four years. One day, during this period, he chanced to find a volume on natural history, containing many colored plates of animals and birds. Eagerly he turned its pages and mastered their contents. Nothing else had ever fascinated him so much.

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The study of animals became his delight. His mother had already taught him to draw, and he copied the plates, tinting them with water-colors, or, when these were lacking, employing pieces of colored silk. At a friend's home he found a complete set, in thirty-six volumes, of Buffon's description of the animal kingdom. To young Cuvier this was a veritable treasure-house of interesting knowledge. Wherever he went, he carried a volume, and every leisure moment was given to its study. Even when he had scarcely entered his teens, he was a well-read zoologist.

Fortunately for Cuvier and the world, when he was fourteen, the sister of Duke Charles of Würtemberg brought the young naturalist to the notice of her brother. Becoming interested in the excellence of the boy's record, the Duke sent him at his own expense to the University of Stuttgart. There for four years he received a training calculated to prepare him for the government service. But, in his leisure hours, Cuvier read the works of Linnaeus and made drawings of birds, insects, and plants. The study of insects was particularly fascinating. In after years he said, "If I had not studied insects from choice, when I was at college, I should have done so later, from a conviction of its necessity." But at the end of his college years, financial difficulties caused him to give up hope of political preferment and to accept a position as tutor in the home of a French family at Caen, in Normandy.

Still fortune favored him. Cuvier found himself at the seashore, where he at once began to study the anatomy of marine animals. The accidental discovery

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of a sea-squid led him to the investigation of shell-fish. He made an extensive classification of worms, which was a real contribution to the zoological knowledge of his time. By chance Cuvier met the learned M. Tessier, and through this new friendship was called to Paris and made professor at the Central School of the Panthéon. Here he wrote his "Natural History of Animals," and so distinguished himself that he was made assistant in Comparative Anatomy at the Jardin des Plantes. Here he began to develop his collection of specimens in comparative anatomy, which is one of his most important contributions to science. Particularly did he become expert in the knowledge of the bones and teeth of animals, both living and extinct. As already stated, he was able to reconstruct the skeleton of an ancient mammoth or mastodon from a single bone. He paid the utmost attention to the peculiar organs of animals, in classifying them into groups. He compared the anatomy of animals now living with that of the fossil remains of species long since extinct. For the first time he proved that every geological epoch is represented by distinct animal forms, having characteristics relating them to the animals of the preceding and succeeding epochs. This was comparative anatomy, the science which Cuvier founded. His discoveries aroused the interest of the whole world, and the publication of his great work on "Fossil Bones" was accorded a popular reception seldom given to a scientific treatise. It lifted Cuvier from the ranks of comparative obscurity into the forefront of scientific leadership. He reclassified the

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animal kingdom on the basis of the structural resemblances of fundamental types, rather than on similarities of outward appearance, as Linnaeus had done. He reduced all the animals of the earth to four principal classes — vertebrated animals, mollusk animals, such as snails and oysters, articulated animals, as insects and crabs, and radiated animals, such as the corals and sea anemones. In his classification he insisted upon the consideration of physiology as well as anatomy.

But although Cuvier clearly recognized that there have been successive geological epochs in the development of the animal life of the earth, he did not accept the theory of evolution. Lamarck had pointed the way, but Cuvier rejected his views, and because of the weight of his influence, kept them from serious consideration. Cuvier held to the older belief in special creation and great catastrophic upheavals, as marking the separation between successive epochs. These views were probably due to his early training and his intense religious zeal. But this failure to recognize the value of a new principle in interpreting the life history of the past does not detract from his important services as a zoologist.

When we consider the wide range of Cuvier's activities in the field of general education and in offices of state, it is difficult to understand how he found time to carry out his monumental researches in science. But every moment of his time was utilized. He read, as he rode through the streets in his carriage. His mind worked so rapidly that what were long and diffi-

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cult tasks for others became short and easy for him. As a lecturer he was the most popular of his time. He held many offices under Napoleon and Louis XVII and was made a Peer of France by Louis Philippe. He succeeded to the head professorship at the Jardin des Plantes and received every scientific honor of his own country and of many others. In personal appearance he was handsome and of noble bearing. By nature he was kind and generous. The early death of his children saddened his life, and possibly hastened his own death at the comparatively early age of sixty-three.

As one writer has said, "the resources of his mind as a mere repository of facts has never been excelled."

Alexander von Humboldt

Goethe, the great German author, once said,

"Alexander von Humboldt has been with me for some hours this morning; what an extraordinary man he is! Though I have known him for so long, I am always struck with fresh amazement in his company. He may be said to be without a rival in extent of information and acquaintance with existing sciences. He possesses, too, a versatility of genius which I have never seen equaled. Whatever may be the subject broached, he seems quite at home in it, and showers upon us treasures in profusion from his stores of knowledge. He resembles a living fountain, whence flow many streams, yielding to all comers a quickening and refreshing draught. He will remain here a few days, and I already feel that I have lived through years in the time."

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Humboldt was the most versatile and widely traveled naturalist of his time. Every phenomenon of Nature aroused his interest, and no one knew better than he how to present the results of his observations in popular form.

In an address given in Boston on the hundredth anniversary of Humboldt's birth, Louis Agassiz said,

"All the fundamental facts of popular education in physical science, beyond the merest elementary instruction, we owe to him. We are reaping daily, in every school throughout the broad land, where education is the heritage of the poorest child, the intellectual harvest sown by him. There is not a textbook of geography or a school atlas in the hands of our children today which does not bear, however blurred and defaced, the impress of his great mind. But for him our geographies would be mere enumerations of localities and statistics. He first suggested the graphic methods of representing natural phenomena which are now universally adopted. The first geological sections, the first sections across an entire continent, the first averages of climate illustrated by lines, were his. Every school-boy is familiar with his methods now, but he does not know that Humboldt is his teacher."

Humboldt was born in the same year with Cuvier, 1769, at Berlin. His father was chamberlain to the Prussian king and his mother was a woman of wealth and culture. He and his brother, William, who also distinguished himself in the diplomatic service, passed their childhoods at the old castle Tegel, on the banks of the Havel, near Berlin. But although his

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surroundings were beautiful and his home one of luxury and refinement, Humboldt did not enjoy his youthful years. The multitudinous restraints under which he was placed robbed him of the joy of what should have been his happiest days. Even in after years, when he came to be the master of Tegel Castle, the unpleasant memories of his boyhood made the place distasteful to him. But he loved Nature, even as a lad, and found his greatest delight in collecting insects and plants and shells and stones. And he became skillful in the art of drawing. But in all the sciences he was self-taught.

"Of the science of botany," he says, "I never so much as heard till I formed the acquaintance in 1788 of Herr Willdenow, a youth of my own age, who had just been publishing a Flora of Berlin. His gentle and amiable character stimulated the interest I felt in his pursuits. I never received any lessons professedly, but I used to bring him the specimens I collected, and he gave me their classifications. I became passionately devoted to botany, and took special interest in the study of cryptogamia. The sight of exotic plants, even when only as dried specimens in an herbarium, fired my imagination with the pleasure that would be derived from the view of a tropical vegetation in southern lands."

Even as a boy, he had the wanderlust, so characteristic of his after years. He longed to go to sea. But at nineteen, under private tutorship, he found himself ready for college and entered Göttingen, where he pursued courses intended to fit him for a life in

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the government service. In his spare moments, he studied botany and made collections of material for use in later publications. Although a naturalist by instinct, Humboldt was fond of the Greek language and regarded it as the "true foundation of all the higher branches of learning." In 1790, he enjoyed a scientific journey through the lower Rhine, Holland, Belgium, England, and France, which resulted in the publication of a number of papers of considerable geological interest. After a short time spent in the School of Commerce at Hamburg, he entered the School of Mines at Freiberg and became an earnest student of geology. He soon became so proficient in his knowledge of minerals and the mining industry that he was appointed superintendent of mines in the two Franconian duchies. After several years in this position, he resigned and gave himself up to travel, first visiting the Alps in the interest of geology and natural history.

In 1799, when Humboldt was thirty years old, he set out upon his most memorable journey. Together with the French botanist Bonpland, he sailed on a Spanish frigate for South America. They stopped en route on the African coast and ascended the Peak of Teneriffe. Of this incident he wrote,

"I returned last night from an excursion up the peak. What an amazing scene! What a gratification! We descended some way into the crater, perhaps farther than any previous scientific traveler. . . . What a remarkable spectacle was presented to us at this height of eleven thousand five hundred feet. . . . At two in the morning we were already on our way

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towards the last cone. The heavens were bright with stars, and the moon shone with a gentle radiance; but this calm was soon to be disturbed. The storm raged violently round the summit; we were obliged to cling fast to the edge of the crater. The wind rushed through the rifts with a noise like thunder, while a veil of cloud separated us from the world below."

His graphic descriptions and charm of style, as well as the thrilling interest of his adventures made him popular as a writer and lecturer.

The travelers proceeded to the north coast of South America and Humboldt was fascinated with the strange scenes, the luxuriant vegetation, and the brilliant colors, declaring that "even the crabs are sky-blue and gold! " In the midst of imminent danger from the wild beasts of the jungle and the crocodiles along the shores, and constantly beset by swarms of mosquitoes, frequently so thick as to darken the sky, Humboldt and his companion traced the Orinoco to its source, and established its connection with the head waters of the upper Amazon. They penetrated where white men had never been before, and made vast additions to the world's knowledge of the plants, climate, and electrical and astronomical phenomena. After a visit of several months to the island of Cuba, the explorers returned and crossed the Andes along a pass described by Humboldt as "so narrow that it rarely exceeds twelve or sixteen inches in width, and for the most part resembles an open gallery cut in the rock." Four times they crossed the Andes and explored considerable portions of Ecuador and Peru.

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Humboldt sailed for home by way of Mexico and the United States. After an absence of five years, and having been given up as dead, he arrived in his native land. All Europe welcomed him. He was elected to membership in the Royal Academy of Sciences in Berlin and in the Legion of Honor at Paris.

Humboldt now made his home at Paris and began the immense task of putting the results of his travels into literary form. A large part of his manuscripts and collections had been lost in shipwreck, but assisted by Cuvier, Gay-Lussac, and other French specialists, he published an elaborate account of his adventures in thirty volumes, illustrated with numerous beautiful plates. The plates alone cost one hundred and seventy thousand dollars, and the price of the set was twenty-seven hundred dollars. Although Humboldt's fortune was now gone, he never lacked the means of support. He was pensioned by Frederick William of Prussia and at length went to reside at the court, where he lectured to the people and traveled with the emperor.

Through his travels and writings, Humboldt had now become famous. His "Views of Nature" was translated into every European language. In 1827 he gave at Berlin a series of extraordinary lectures on physiography. At all times zealous for the advance of science, he labored for international co-operation in the interest of scientific observation. On an expedition to the Ural Mountains and the northern interior of Russia, for the emperor of that country, he discovered diamonds and other precious stones, whose existence he had predicted from his knowledge of

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geology. On this trip, lasting twenty-five weeks and covering nine thousand miles, he corrected many erroneous views as to the physical geography of that little-known region. He regarded his "Cosmos" in thirty-six volumes as his greatest literary work. In it he gave his conception of the physical universe. It was translated into many languages and made a deep impression upon the scientific thought of his time.

Humboldt contributed to nearly every branch of science. He was quick to perceive the merits of young scientists, and it was his delight to befriend them. He died in 1859 at the goodly age of four score years and ten, and will always be remembered as a foremost member of that group of scientists who heralded the modern era.

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CHAPTER VIII

MASTERS OF STEAM

With the masters of steam came the beginnings of the modern age of power. These men who harnessed the motive power of steam to the performance of the world's work led their fellowmen from a day of tiny accomplishment into an era of vast achievement. Much of the drudgery of human toil has vanished. Barriers to travel and commerce have disappeared. The earth has grown smaller. Its waste places have been brought within the confines of civilization. Industry has been revolutionized. The larger commercial and social intercourse of this new age broadened men's minds, and has banished forever the provincialism of the past. More important than the French Revolution and the widespread political upheavals of a century and a quarter ago was the introduction of steam into the workshops of the world.

James Watt

For more than a century the name of the Scottish inventor of the steam engine has been a household word the world over. Who has not pictured Watt as a lad sitting beside the fireplace, fascinated by the

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behavior of the steam, as it lifted the lid of the kettle? Whether this tale be true or false, it is certain that the idea of running machinery by steam had haunted James Watt from his youth up. But little did he dream of the vast industrial changes that his future invention would bring about.

Born at Greenock on the River Clyde in 1736, not robust, shy and retiring as a child, Watt early exhibited a strong mechanical bent. Following this inclination, he selected the trade of instrument maker and apprenticed himself to a master in London. Because the climate of London did not agree with him, he returned to Scotland, when his apprenticeship had been completed, and established himself as instrument maker at the University of Glasgow.

Here in his little shop there was brought to him one day for repair a model of the Newcomen steam engine. It must be remembered that Watt was not the first man to build a contrivance for utilizing the expansive force of steam. As early as 1688 Denis Papin, a French professor at the University of Marburg, had moved a piston in a cylinder by the aid of steam. Ten years later Thomas Savery of England invented a crude sort of steam pump for lifting water from the coal mines. Crude, clumsy, wasteful, this first practical device for applying steam power bore about as much relation to a modern engine as an ox cart does to the Twentieth Century Limited. Yet it was a marvel in that early day, and of vast significance to later inventors, because it pointed the way. At the beginning of the next century Thomas Newcomen. an

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English blacksmith, devised a half-steam, half-atmospheric engine, which for many years did valiant service in pumping water from the deep mines of the island kingdom. Still, this engine was of tortoise speed. It developed little power, and, worse yet, at every stroke four fifths of the steam was wasted in needless condensation.

This was the engine that in 1763, had been brought to Watt for repair. He saw at once the frightful waste, and then and there resolved to build an engine that would eliminate it. In the Newcomen engine, at the top of every stroke, cold water was injected into the cylinder to condense the steam and create a vacuum. The atmospheric pressure forced the piston to the bottom of the cylinder, and, more steam being admitted, the operation was repeated. But in each cycle most of the energy in the steam was wasted in reheating the cylinder. How to overcome the waste was the problem. It seems easy now. Yet it baffled Watt for two years. While building to prosperous proportions his business as instrument maker, he at the same time constantly experimented with steam devices. Day and night this puzzle haunted him. Believing that "Nature always presents some weak side" to the would-be discoverer of her mysteries, Watt persisted in his quest. One bright Sunday afternoon, early in 1765, he went for a walk. As usual his thoughts were upon the problem of the steam engine. Of a sudden the solution flashed into his mind. In that moment the first step in the invention of the modern steam engine was taken. Before he had com-

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pleted his walk, he states that "the whole thing was arranged in my mind."

His idea was to connect to the working cylinder a vessel into which the steam was to be exhausted for condensation, thereby keeping the cylinder constantly hot. The following morning with a brass syringe borrowed from the college laboratory, and a tin can for a condenser, Watt tried out his scheme, and to his great joy found that he was on the right track. He set to work enthusiastically to build a model. But with unskilled workmen and the lack of tools suited to his needs, he could not make a steam-tight cylinder. Still, imperfect as it was, his engine was many times more efficient than its Newcomen predecessor. Forming a partnership with Dr. Roebuck, an ironmaster of Glasgow, he obtained much-needed funds for his work. In 1769 he had a working model upon which the government granted him a patent. In that same year, Watt built an engine of huge proportions, but faulty workmanship on the part of his mechanics made it only a partial success. Business reverses made it impossible for Dr. Roebuck to assist him further. Heavily in debt and without funds, the death of his wife and counseler at just this time added sorrow to his burdens. Still out of the blackness of the night success smiled upon him once more. He formed another partnership with Mathew Boulton, a prominent merchant of Birmingham, and a little later invented his double-acting engine, the first one-hundred per cent steam engine ever built. In it he dispensed with the atmospheric pressure, and admitted steam

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alternately on each side of the piston. To it he added the governor for controlling speed, and a device to convert the to-and-fro motion of the piston into the rotary motion of the flywheel. So superior was it to the Newcomen engine that its earlier rival quickly passed into disuse. Watt and Boulton built a large factory and established a prosperous business. Success had come and with it a new day in the industrial life of the world.

Since the inventions of Watt, only two new principles have been added to the steam engine. They are the use of high-pressure, superheated steam, and the compound engine, in which two, three, and sometimes four cylinders, each of a larger diameter than the preceding, are employed.

A century has passed since the time of Watt, but the world still lives in the Age of Power which his invention brought about.

Robert Fulton

Had you been a native of Lancaster, Pennsylvania, during the War of Independence, you could not have failed to make the acquaintance of an energetic lad known far and near as "Quicksilver Bob." He was given this queer nickname because of his fondness for mercury with which to experiment. He was always inventing something. He built paddle-wheel boats. He experimented with firearms. He designed machinery. He became an architect and painter. At seventeen, Robert Fulton left his native town to

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seek fame and fortune in this and other lands. Going to Philadelphia, he hung out his sign as a painter of portraits and miniatures. Gifted with many accomplishments and a winning personality, progress was easy. He won the friendship of Benjamin Franklin and profited by his wise counsel. Hearing much of France and England, Fulton decided to cross the ocean, which he did in 1786. There he embarked upon that career which made him the friend of artists, noblemen, and kings, and his name familiar on two continents.

While in England, Fulton made a number of inventions, including a machine for spinning flax, a device for twisting hemp rope, and a shovel for scooping out the earth in building canals and aqueducts. At the request of the Earl of Stanhope, whose friendship he had won, he interested himself in the possibility of propelling boats by steam. But nothing came of this suggestion for a number of years. In the meantime, he turned his attention to the invention of torpedo boats, with which he succeeded in blowing up two old brigs assigned for this test. Being unable to interest either the French or British governments in these new weapons of warfare, Fulton turned once more to the problem of applying steam to the art of navigation.

He went to England and studied first hand every detail of the construction and working of Watt's double-acting steam engine. Making such changes in the design as seemed necessary to adapt it to his purpose, he ordered a large engine to be built and shipped

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to America. More important still, Fulton had entered into partnership with Chancellor Livingston, one of America's wealthiest and most prominent citizens, for the purpose of building a successful steamboat. This was in 1806, but several years earlier he had built a small model steamboat, which he operated successfully on the Seine in France.

Fulton returned to America and in the following winter and summer built the *Clermont,* named after Livingston's country-place on the Hudson. It was a substantial boat of 150 tons' displacement — nearly twice as large as the ships in which Columbus crossed the Atlantic. Casting aside the curious devices of his predecessors, he resorted to his boyhood idea of side-wheel propellers to drive his boat through the water. A short trial trip satisfied him of the successful outcome of his work. Then on August 17, 1807, Fulton began that historic trip up the Hudson, which was destined to banish the sailing vessel from the seas and to revolutionize the ways of ocean travel. Unmoved by ridicule, and the fears of the countryside, Fulton piloted his "fire-belching monster" against wind and tide from New York to Albany. We may imagine his triumph. Fishermen forsook their nets. The populace stood aghast. Amazement, incredulity, and superstition swayed young and old. At nighttime the myriad of sparks rising through the boat's funnel from the roaring pinewood fire below conjured up visions of the Day of Judgment and perhaps the life to come.

Before he died, at the early age of fifty-one, Fulton had built seventeen steamboats, and his regular line

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of packet steamers soon became a welcome and familiar sight along the Hudson. So punctual were they in their running time that time came to be reckoned from their arrival and departure.

Yet Fulton was not the first to experiment with steamboats. The Marquis de Jouffroy in France, Symington in Scotland, and Fitch, Rumsey, and Stevens in the United States had preceded him. But just as Watt, taking the crude devices of previous workers, fashioned them into a practical mechanism, so did Fulton, working above the failure of others, become an acknowledged master of the Steam Age, and the inventor of the first successful steamboat.

George Stephenson

It is difficult to realize that but one century ago the stage coach was still the fastest means of land conveyance. Steam had only begun to be used for navigation. The sailing vessel was supreme upon the seas. People lived in isolation. The earth was immense. Distances were reckoned in days and weeks, not in minutes and hours. The Great West of unexplored forest, plain, and mountain stretched four thousand miles toward the setting sun. Yes, the world was young. The Age of Steam had hardly touched it. True, the groundwork had been laid. The materials were at hand. And in George Stephenson the world found the workman who took the imperfect inventions of his predecessors, and, fusing them with the products of his own genius, created the steam loco-

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motive, which for a hundred years has snorted defiance at every obstacle in its way of conquest.

The first important use to which Watt's perfected engine had been put was lifting coal from the mines and hauling it by means of stationery engines from the mine shaft to the shipping point. But manufacturing was a rapidly-growing industry in England and better means of transportation were becoming imperative. Numerous inventors experimented with steam-driven vehicles. In 1802 Richard Trevithick attached a high pressure engine to a four-wheeled wagon and successfully operated it on the streets of London. But it could go no faster than a slow horse, and soon pounded itself to pieces. A number of clumsy, slow-moving engines had been built for propelling coal cars at the mines. Many people were certain that steam could be successfully applied to the solution of the transportation problem, but where was the man who could do it?

The answer was in George Stephenson. Stephenson was born in 1781 and had worked in the mines from his boyhood up, advancing steadily from the post of "slate-picker" to that of chief engineer at the Killingworth Colliery. Stephenson believed that he could build a better locomotive than any that had yet been made. Having won the confidence of his employers, Lord Ravensworth, the principal partner, agreed to finance the undertaking. The result was the *Blutcher*, a locomotive that would haul a loaded train of about thirty tons' weight up a grade of one foot in four hundred and fifty, at the rate of four miles an hour.

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This was improvement, but still imperfection. A second locomotive was begun in the following year, 1815. Here Stephenson adopted an expedient which was of tremendous importance. He turned the exhaust steam from the cylinders into the smokestack. This so increased the draft of his fire that the capacity of the boiler to produce steam was greatly enlarged. Within a few years Stephenson's locomotives were being used at all the leading collieries of England.

Stephenson next turned his attention to the possible use of steam on the public highways. In 1821 his services were secured for the construction of the Darlington and Stockton line, covering a distance of twenty-one miles. In 1825 the road was opened. It was a great event, not only for the populace, but for the success of steam locomotion. A train of thirty-four cars, weighing about ninety tons, and carrying six hundred passengers, made the trial trip. Stephenson drove the locomotive himself, and at times the train made the unheard-of speed of twelve miles an hour. The road had been built to carry freight, but in a short time it became the most popular means of travel between the two cities.

Then a road was built between Liverpool and Manchester. But difference of opinion existed among the directors as to what the motive power on the new road should be. Stephenson was practically the only advocate of steam locomotion in preference to horses, or stationary engines and a cable system. All sorts of objections were raised to the use of locomotives, one of the chief being that they would frighten the

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horses along the route. But at length the locomotive won, and the directors offered a prize of five hundred pounds to the builders of a locomotive that on a certain day should best perform certain specified duties.

Stephenson and his son Robert built for this contest the now famous *Rocket*. In its construction radical changes from former types were made. Great difficulties were overcome. At times the obstacles seemed insurmountable. But defeat was not to be found in their vocabulary. In October of 1829 the day of the contest came. Three other engines were entered, but the contest quickly narrowed down to the *Novelty* and the *Rocket*. Although the *Novelty* made at times a speed of twenty-four miles an hour, her machinery repeatedly broke down and the field was left to the *Rocket*. With it, Stephenson performed marvelous feats for those days. Carrying thirty-six passengers, he made a speed of thirty miles an hour. With thirteen tons of freight he covered thirty-five miles, including stops, in an hour and forty-eight minutes. The *Rocket* fulfilled every condition of the contest and Stephenson was awarded the prize.

Lines of railroad multiplied. Receipts from freight and passenger traffic outstripped the wildest expectations. Prejudice vanished and enthusiasm knew no bounds. Stephenson continued to improve his engines and soon became the world's leading authority on locomotive construction. He was chief engineer on half a dozen lines and was called into consultation by kings of foreign lands. He died in 1848, second only to Watt in his achievements of putting steam to work.

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The Steam Turbine

The story of steam would not be complete without mention of the steam turbine, invented in 1884 by Mr. C. A. Parsons, an Englishman. This engine makes use of the direct impact of the molecules of highly heated steam on numerous little curved blades, arranged in rows and attached alternately to a long, slender, rotating shaft and the rigid, outer jacket of the engine. The turbine has now been adopted almost exclusively in ocean liners and in the navies of the world. It has also proved the ideal engine for the generation of electric power.

We still live in the Age of Steam, and until men have learned to harness the energy of the sun or tap the inexhaustible reservoirs of sub-automic energy, the world will continue to derive much of its motive power through the agency of steam. For electric power, it must be remembered, is generated largely by steam.

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CHAPTER IX

GLIMPSES OF FAMOUS CHEMISTS

At the beginning of the last century the new-born science of chemistry was adrift on an uncharted sea. True, many discoveries had been made. Only an echo of alchemy remained. The false phlogiston theory of combustion was near its death. Men with the spirit of modern research were coming to the fore in every capital. But the various branches of chemistry were all to be developed. Their applications to industry had not even been glimpsed. The age of creative chemistry was still in the future. But scientific investigation had begun, and many illustrious workers contributed to the progress of this notable century.

John Dalton

A master of surveying and navigation at the age of eleven, teaching the village school at twelve, assistant principal of an academy at fifteen, experimental scientist at twenty, and at thirty-five world renowned philosopher and author of the most important single generalization in the history of theoretical and practical chemistry — such was the career of John Dalton, the father of the Atomic Theory of the Elements.

Dalton was born at Eaglesfield in Cumberland, England, in 1766, the year in which Cavendish made

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his famous discovery of hydrogen. For several generations his ancestors had been Quakers and Dalton kept the faith. For many years he followed the life of a schoolmaster, devoting all of his spare time to experimental work. In 1787 he began to make systematic observations of the weather, keeping the record until the day of his death fifty-seven years later. Indeed, it was this work that led him to his majestic conception of the atoms. In 1793, he became professor of mathematics in a newly established college at Manchester. After the beginning of the century, he supported himself by private tutoring, until the last decade of his life, when his services to science were rewarded by a substantial pension from the king. Three large volumes preserve the record of his experimental work in physics and chemistry.

An interesting episode in Dalton's life was his discovery of color-blindness. Until he was twenty-eight years old, he had never noted this defect in his sight. On the occasion of a visit to his mother, he thoughtfully purchased for her a pair of silk hose. Upon presenting them, his mother remarked, "Thou hast brought me a pair of grand hose, John; but what made thee fancy so light a color? I can never show myself at meeting in them." Dalton imagined that they were an orthodox gray and called in his brother for verification. His brother also agreed that they were gray. Then the neighbors were asked to settle the dispute. The verdict was "varra fine stuff, but uncommon scarlety." Both he and his brother were convicted of color-blindness, and Dalton gave so much study to

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this defect of vision that it has ever since been known as *Daltonism*. On the occasion of his receiving a degree from Oxford, he wandered about the university grounds for several days after, garbed in his scarlet robes. When asked about this, he remarked that the color of his gown seemed to him the same as that of the green leaves.

From his study of gases and their compositions, which he determined experimentally, Dalton came to the far-reaching conclusion that *elements are made up of smallest particles called atoms, and that chemical compounds of the elements are formed by the union of these atoms in simple numerical proportions*. This is the Atomic Theory. From the day of its announcement to the present moment, it has been a guiding principle of chemical investigation. It gave a solid theoretical basis for studying the chemical behavior of the elements and has led to many sweeping discoveries. It rests, not upon speculation, as did the Greek theory, but upon experimental fact. By explaining the meaning of observed facts and leading to the discovery of new ones, it has fulfilled the supreme test of any hypothesis. Each new revelation only serves to establish more securely the work of this simple Quaker philosopher.

JÖNS JAKOB BERZELIUS

In 1779 was born in a little hamlet of Sweden a lad who was to be known for nearly half a century as the "czar of chemistry." It is interesting to know

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that, when Jöns Jakob Berzelius graduated from the high school, the authorities handed him a certificate stating that he "justified only doubtful hopes." At the University of Upsala, too, where he studied medicine, he failed in the final examination in chemistry and was allowed to graduate only because of his better showing in physics. But chemistry in that far-off time had not become a science. No university professors were competent to teach it. Berzelius had turned in disgust from the crude, alchemistic teachings presented by ignorant theorists and labeled as chemistry. Yet in his heart he yearned for the truth. His great passion was to become a chemist. Having been refused permission to use the college laboratory, he began to experiment in the small, windowless room of his student's apartment. "One day," he says, "as I was making fuming nitric acid and noticed some gas escaping, I collected it over water in some bottles that I had at hand, to find out, if I could, what this gas was. I suspected oxygen, and seldom have I had a moment of such pure and heartfelt joy as when the glowing splint placed in the gas burst into flame, and lighted up my dark laboratory." Joy keener, no doubt, than any experienced in the moments of the great discoveries with which he later enriched the subject.

Experiments on the action of the galvanic current soon gave him a reputation in his own country and won him an assistant professorship in the University of Stockholm. Here and in two other institutions he continued to teach for many years. But it was in his own private laboratory that he carried on those re-

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searches which made him famous throughout Europe. Here, too, came to him those pupils who, after studying under the master, went away to spread his teachings in other lands.

While Berzelius enriched every branch of the subject by original work, it was in the field of atomic weights that he rendered his most distinguished service. After Dalton had pointed out that the atoms of the elements enter into combination in proportion to certain definite relative weights, it became a matter of the utmost importance to determine these atomic numbers. Even before Berzelius had learned of Dalton's theory, he had taken up this task as his life work, and with a zeal for accuracy and thoroughness unsurpassed he has made every chemist his debtor. He determined the atomic weights of more than fifty of the elements, in many cases obtaining values almost identical with those resulting from the most refined of modern methods. After Lavoisier, Berzelius was the first man to approach chemistry with a balance, and he was really the first great quantitative chemist.

In Berzelius' time no laboratory instruction was given in any of the universities of Europe. As his fame spread abroad, there came to study under him in his simple rooms at Stockholm students who in after years were numbered among the most distinguished chemists of the century. It was as a master teacher, as well as an original worker, that Berzelius made one of his most important contributions. The noted German chemist Wöhler, as a young man, went to study with him. Arriving at night he knocked at

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the door of Berzelius' residence. He tells us that his heart beat fast as the door was opened by a large man with florid complexion, who proved to be Berzelius himself. Entering the laboratory, Wöhler could scarcely believe that he was in the place where so many important discoveries had been made. And he was amazed to find that this laboratory contained no water, no gas, no draft-places, no ovens. There were two plain tables, a blow-pipe, a few shelves of bottles, a little simple apparatus, and a couple of balances. We should hardly call it good home laboratory outfit for a grammar-school boy now. Yet in it many new elements and compounds had been discovered. Atomic weights had been determined and the whole groundwork of theoretical chemistry rebuilt. When a real genius sets to work, his material requirements are few.

To Berzelius we also owe our symbols for the elements and the present system of chemical formulae. Before his time H_2O would have meant nothing to the wisest chemist. He was also a prodigious writer. His textbook ran through five editions and was translated into every language of Europe. In shaping the course of chemistry, its influence was immense. Before his death in 1848, he had been honored by his government and by practically all the scientific societies of his time.

Justus Liebig

At Darmstadt, Germany, in 1803, just a year before Priestley's death and at the very beginning of Davy's early triumphs, was born a man destined to have a

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more profound influence upon the teaching of chemistry than anyone who has ever lived before or since. Justus Liebig acquired his taste for chemistry while still a lad. His father had a small laboratory in which he prepared paints and many of the common chemicals. In this laboratory and in the workshops of his native town, he began to study chemical phenomena. Obtaining access to the court library, he devoured all the books on chemistry, taking them in the order in which they happened to stand on the shelves. When he was sixteen, he was apprenticed to an apothecary. Here he became interested in the preparation of the explosive, silver fulminate. But in so doing he blew off a portion of the roof of the apothecary shop, and as a result effectually removed himself from that business. He then begged his father to send him to the university, and in 1820 young Liebig entered the University of Bonn, later transferring to Erlangen.

Liebig's purpose was to study chemistry, but he was confronted with the same difficulty that had discouraged Berzelius. Real chemistry was not taught in the German universities. Germany, which was in later years to become the home of research chemistry, offered no opportunities in this field at that time. Learning that from the brilliant group of French chemists he might obtain the instruction which he coveted, Liebig, after some difficulty, succeeded in securing a traveling scholarship permitting him to study in the French capital. There by great good fortune he won the friendship of Alexander von Humboldt, who introduced him to Gay-Lussac, the leading

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chemist of Paris. Under this French master, Liebig obtained the thorough training that was to make him the first great German chemist.

Returning to his native land, Liebig became professor of chemistry at the University of Giessen. It was the first real professorship in the subject to be established in that country. Finding no laboratories, Liebig converted a deserted barracks to that purpose. There he gave the first systematic laboratory instruction that had ever been given in any school or university of the world. Davy and Faraday worked alone. No instruction was given in England. At Paris only a few private students, such as Liebig had been, were permitted to study. Berzelius received a few, but they were mostly advanced students. College courses with supervised laboratory work were unknown. Liebig determined to correct all this, and the splendid work that he inaugurated at Giessen has been the model down to the present day.

Liebig was a remarkable instructor. He infused into his students his own fiery, impetuous spirit. He stimulated them with the charm of his own personality, and inspired them with enthusiasm. He spared no pains in giving individual instruction, but he made his pupils think for themselves. He threw them upon their own resources, and expected and received much from them. Students flocked to his laboratories from all over the world. He became the greatest science teacher of his day. Scores of the most distinguished chemists of the succeeding decades studied with him. One of his pupils has said of him, "What a boon it

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was to drink the pure breath of science, as it flowed from Liebig's lips! Each word of his carried instruction. Every intonation of his voice bespoke regard. His approval was a mark of honor."

But Liebig was not only the master teacher of his time. He was an original research worker of the first magnitude. After Scheele he was the next great organic chemist and the founder of the modern science. He perfected methods of organic analysis, which are standard to the present day. In physiological and agricultural chemistry, he was a pioneer.

Impetuous, passionate, bitter in his denunciations, but with a keen sense of justice, the supreme purpose of his life was to discover the truth. One of the most beautiful memories in the history of science is the life-long friendship that existed between Liebig and his contemporary, Frederick Wöhler, who in many ways was his direct opposite in character. Liebig died in 1873, renowned in every land where chemistry is known.

Jean Baptiste André Dumas

Contemporary with Berzelius, Liebig, and Wöhler was the French chemist Dumas. Born at Alais in 1800, he early showed a strong bent for natural science, and, like so many other famous chemists, he was apprenticed to an apothecary. But he soon left his native town for Geneva, where he entered a laboratory for the manufacture of drugs. His latent enthusiasm was fired by the brilliant discoveries of Davy,

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Berzelius, and his own countryman, Gay-Lussac. Soon Dumas began to experiment for himself. Having made what he thought to be an original investigation of the water of crystallization held in a number of salts, he hastened with his manuscript to the famous French chemist de la Rive. When de la Rive had come to the end, he said, "Is it you, my boy, who have made these experiments?" "Certainly." "And they have taken you a good deal of time to perform?" "Of course they have." "Then I must tell you that you have had the good fortune to meet Berzelius on the same field of research. He has preceded you; but he is older than you, and you ought not to bear him ill-will on this account. Come along and breakfast with me." But associated with Prévost, Dumas shortly succeeded in carrying out researches in physiological chemistry that commanded the attention of the scientific world. When twenty-two years of age an incident occurred that changed the whole course of Dumas' life. He has told it himself.

"One day," he said, "when I was in my study completing some drawings at the microscope, and it must be added, rather negligently attired, in order to enable me to move more freely, some one mounted the stairs, stopped on my landing, and gently knocked at the door. 'Come in,' said I without looking up from my work. On turning round I was surprised to find myself face to face with a gentleman in a bright blue coat with metal buttons, a white waistcoat, nankeen breeches, and top-boots. This costume, which might have been the fashion under the Directory, was

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then quite out of date. The wearer of it, his head somewhat bent, his eyes deep-set but keen, advanced with a pleasant smile, saying, 'Monsieur Dumas?' 'The same, sir; but excuse me.' 'Don't disturb yourself — I am M. de Humboldt, and did not wish to pass through Geneva without having had the pleasure of seeing you.' Throwing on my coat, I hastily reiterated my apologies. I had only one chair. My visitor was pleased to accept it, whilst I resumed my elevated perch on the drawing stool. Baron Humboldt had read the papers published by M. Prévost and myself on Blood and was anxious to see the preparations I had by me. The wish was soon gratified. He was fond of talking; he passed from one subject to another without stopping. . . . I listened with a strange delight; a new horizon began to dawn upon me. . . . At the end of a few days Baron Humboldt left Geneva. After his departure the town seemed empty to me. I felt as if spell-bound. The memorable hours I had spent with that irresistible enchanter had opened a new world to my mind. I had been more especially impressed with what he had told me of Parisian life."

As a result of this happy experience, Dumas soon found himself in Paris. Shortly after he was invited to read a paper before the Academy of Sciences. When he had finished reading it, a venerable looking man on the opposite side of the room rose and approached him. "Monsieur Dumas, will you do me the honor of dining with me on Wednesday next?" The invitation was politely accepted and the venerable gentleman returned to his place. "With whom am I

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to dine?" Dumas inquired of a bystander. "Did you not know — it is M. de Laplace?" Had it been the emperor himself, Dumas could not have been more delighted, for Laplace was one of the foremost scientists of the French capital.

From that day until his death in 1884, Dumas was a leading figure in the development of theoretical and analytical chemistry. He was one of the pioneers in organic work and a teacher of vast power and influence. He found time to devote to public service and to the public health. He was a foremost member of that brilliant group that has made the chemistry of the last century memorable.

Dmitri Ivanovitsch Mendeléeff

One would hardly expect to find a frontier town in far-off Siberia the birthplace of a famous scientist. But such is the case. Mendeléeff, the most noted Russian chemist, was born at Tobolsk, Siberia, in 1834. His father was Director of the College at that place, but shortly after the birth of his son he was stricken with blindness and died of tuberculosis. When Mendeléeff was sixteen, his mother removed with him to St. Petersburg, where she succeeded in entering him in college. Assisted financially by the government, Mendeléeff was able to finish his college course. But his lungs were so affected that his doctors ordered him to go to the southland, and gave him only a few months to live. He completely recovered, however, and lived to the age of seventy-three. After

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some years of vigorous research work and teaching, Mendeléeff studied in France and Germany, returning to Russia to receive the degree of Doctor of Science and the appointment as Professor of Chemistry at the Technological Institute.

In 1869 Mendeléeff discovered a fundamental relationship between the properties of the elements and their atomic weights, second only in importance to the Atomic Theory itself. Up to this time no chemist had succeeded in disclosing any general principle welding the elements and their compounds into a coherent system. A number had approached the problem but no one had solved it. There was a wealth of isolated chemical facts but no law of harmony. Back of this seeming chaos, Mendeléeff perceived a plan. He had found the key to the ante-room of the atomic mysteries. He unlocked the door and behold, law and order reigned supreme. As the result of a prodigious amount of the most painstaking experimentation, he showed that the properties of an element depend upon its atomic weight. Arranged in the order of their atomic weights the elements naturally fall into periods and groups, in which all the elements of the same group exhibit a striking similarity of properties. In the beautiful language of Robert Kennedy Duncan, "Just as the pendulum returns again in its swing, just as the moon returns in its orbit, just as the advancing year ever brings the rose of spring, so do the properties of the elements periodically recur as the weights of the atoms rise." This generalization is known as the Periodic Law. In the light of its revelation men

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seemed to catch a glimpse of the eternal purposes of the Great Architect. They knew that one more step had been taken in unravelling the ages-old secrets of energy and matter. Back of it there seemed to be a harmony and purpose that men might hope to understand.

There were a few exceptions to the law, and some blank spaces in the table, but most of the exceptions have since disappeared, and the discovery of new elements has filled in many of the spaces. So strong was Mendeléeff's faith in the law that he predicted the discovery of three new elements and lived to see his prophecy verified. The properties of these elements and their compounds proved to be practically identical with those he foretold. Nowhere else in the annals of science is there anything to compare with it, save in the discovery of Neptune, and the confirmation of Einstein's theory of gravitation.

Mendeléeff was the author of a textbook of chemistry, which is even today, after a lapse of half a century, a perennial source of inspiration. As a teacher he was the equal of Liebig. Higher commendation no man could ask.

Many other chemists have added luster to this golden age of chemical discovery. Perhaps these brief sketches will stimulate the reader to explore for himself the field of chemical romance and to learn more of the biographies of its founders.

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CHAPTER X

TWO PIONEERS OF MEDICINE

Edward Jenner

Until the close of the eighteenth century small-pox was the most dreaded scourge of the human race. Again and again this pestilence, sweeping over the earth, claimed by death one-tenth of the population of Christendom. According to an old saying, "From small-pox and love but few remain free." The unpitted face had come to be almost an exception. But Edward Jenner, an English physician, in common with many others had noticed that those who had suffered from the similar but milder form of disease known as cow-pox were thereby rendered immune to small-pox. Realizing what a boon to his fellowmen a preventive or cure would be, Jenner determined to make a searching investigation of the whole matter. It was the first important medical research ever undertaken, and the keenness of vision displayed and the enlightened methods employed would do credit even to the scientific investigators of our own day.

Jenner concluded that cow-pox has its origin in a disease common to horses and manifesting itself in a swelling of the heel, from which exudes a limpid fluid having peculiar properties. This fluid he found would infect cattle with cow-pox, and human beings

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with a disease similar to small-pox. His observations led him to believe that the disease was spread from the horse to cows and thence to individuals, because the same person who dressed the sores of the horse frequently assisted in milking, without taking the proper precautions about washing. The symptoms and progress of the disease, Jenner studied in great detail.

Then in 1796 he inoculated a patient with the virus of cow-pox and two months later inoculated the same subject with the virus of small-pox. This was a bold experiment. Jenner was dealing with human life, the most precious possession of the race. But like Pasteur in his conquest of rabies nearly a century later, he had the courage born of knowledge. Incidentally, the patient must have had some sort of courage, too. Together they triumphed. The patient showed no signs of the fatal malady. Without the preventive vaccination, death would have been almost certain. Still Jenner continued his investigations for two years before publishing his discovery. Then, fortified with abundant proof, he took the world into his confidence. One might have expected that the scientific fraternity would look with skepticism upon his announcement. It did not. Seldom has a discovery been given a more enthusiastic welcome. Within six years it had penetrated to the remotest parts of the earth. Like drowning people, men looked to the practice of vaccination as toward a lifeboat coming to their rescue. Clergymen advocated it from their pulpits. The name "Vaccinov" was given to the first child to be

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vaccinated in Russia, and he was educated at public expense. In Germany Jenner's birthday was celebrated as a national festival. His name was honored by kings and the leading scientific societies of his own and other lands.

From being the most dreaded of diseases small-pox soon became the most easily controlled. It was a victory that will make the name of Jenner secure in the history of medical science.

Dr. William T. G. Morton

"I have felt no pain." So spoke a young man in the Massachusetts General Hospital on October 16, 1846, after having undergone what would formerly have been a painful surgical operation. A miracle seemed to have been wrought. Under the influence of ether, administered by a young doctor, William T. G. Morton, the patient had gone to sleep, and had awakened to the pleasant comprehension that the ordeal was over. The open skepticism of the medical students and physicians who had gathered to witness the "fiasco" quickly changed to wondering admiration. It was the greatest triumph in the history of surgery.

Ever since Davy had experimented with laughing gas at the beginning of the last century it had been theoretically possible to banish pain in minor surgical operations. Still a generation passed before any practical attempt was made to carry out this idea. Then, in 1836, Dr. Horace Wells, a dentist of Hartford,

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Connecticut, began to experiment. He had observed that a person under the influence of liquor seemed to experience little pain, even when severely beaten. He knew, too, that soldiers in battle are often badly wounded, and yet have no knowledge of the fact at the time. Dr. Wells attended a lecure in which a public demonstration was given of the physical effects of laughing gas. He observed that a man under the influence of this gas seemed to feel no pain from bruises inflicted upon his body. This set Wells to wondering if the gas might not be used as anaesthetic, for the painless extraction of teeth. He determined to try the experiment. The next day, he placed himself under the influence of this peculiar compound and with the assistance of a brother dentist extracted one of his own teeth. The operation was painless. He successfully repeated the test some fifteen times on a number of patients and then applied for permission to make a demonstration before the medical class of Harvard College. His request was granted, but unfortunately he did not administer enough of the gas. At the first application of the instrument, the victim roared with pain. Amid the confusion resulting from the immoderate ridicule of the students, Wells retired from the scene, and did nothing more toward the introduction of his anaesthetic.

Another young dentist, Dr. Morton, was experimenting in this same field. He had tried wine and brandy as well as laudanum and opium, but all his experiments had given results unsatisfactory to him, though perhaps not entirely devoid of charm for his

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patients. Then by chance he had observed the demonstration by Dr. Wells and, as he watched it, there flashed into his mind the idea of inhaling ether. He first experimented upon himself with a mixture of opium and ether, but received so severe a headache that he did not repeat the attempt. Whether or not pure ether was safe to breathe was the big question. His medical books told him that the drug produced a stupefaction from which it was doubtful whether the patient could be restored. Determined to try this out, he obtained a quantity of ether and retired to the country. His first test was on a dog. He saturated a handful of cotton with the liquid and held it to the dog's nose. Morton says, "In a short time the dog wilted completely away in my hands, and remained insensible to all my efforts to arouse him by moving or pinching him." Much to Morton's joy, in a few minutes the dog had completely recovered and was frisking about as usual. Next he tried the ether upon himself. Gradually he sank into an unconsciousness. Morton now felt certain of the success of his discovery and determined to put it to practical test.

"One evening," says the discoverer, "a man entered the office suffering great pain, and wishing to have a tooth extracted. He was afraid of the operation and asked if he could be mesmerized. I told him I had something better; and saturating my handkerchief with ether, gave it to him to inhale. He became unconscious almost immediately. It was dark, and Doctor Hayden held the lamp, while I extracted a firmly-rooted bicuspid tooth. There was not much alteration

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in the pulse, and no relaxation in the muscles. He recovered in a minute and knew nothing of what had been done to him."

Morton's crowning triumph was the successful use of ether in the operation at the Massachusetts General Hospital, which has already been mentioned. As rapidly as possible in that day the news was spread to all the world. Save for Jenner's discovery of vaccination a half century before, nothing of equal significance in medical research had ever occurred. The ill-considered opposition of a few visionless minds, both of the medical profession and the church, was quickly stifled, and painless surgery has come to be one of the most important triumphs of medical science.

It should be noted in the interest of historical accuracy that Dr. Crawford W. Long, a physician in a small Georgia town, had employed ether in minor surgical operations even before Morton's discovery. But he did not publish his results, and it is certain that Morton knew nothing of these experiments.

Within a few months after the introduction of ether, a Scotch surgeon, Sir J. Y. Simpson, discovered the anaesthetic properties of chloroform, a drug which was prepared for the first time by the German chemist, Justus von Liebig. Certainly no greater boon has come to mankind than this magical stilling of pain by means of anaesthetic drugs.

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CHAPTER XI

LOUIS DAGUERRE AND ALVAN G. CLARK

Louis Daguerre

"I have seized the light! I have arrested his flight! The sun himself in future shall draw my pictures!" Thus exclaimed Louis Daguerre, the French scene-painter, in the moment of his discovery of how to develop photographic prints. For more than a decade he had been striving in every conceivable way to photograph images by the chemical action of light.

The Swedish chemist, Scheele, had described the action of light on silver salts as early as 1777. A quarter of a century later Thomas Wedgwood, son of the famous potter, working with Sir Humphry Davy, produced silhouettes of ferns and engravings upon paper sensitized with silver nitrate. But unless kept from the light these pictures quickly darkened and disappeared. No process for fixing the print was known. Davy states that "nothing but a method of preventing the unshaded parts of the delineations from being colored by exposure to the day is wanting, to render the process as useful as it is elegant." These early investigators experimented with the *camera-obscura,* a light-tight box having a small aperture upon

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one side. The light reflected from some object through this small opening produces an inverted image upon the back wall of the box. But the images described upon silver nitrate paper placed in this camera were too faint to be of value.

Joseph Nicéphore Niépce, a country gentleman of France with a taste for scientific pursuits, was the first man to achieve anything like success in fixing the images produced by sunlight. Yet his work was but a stepping-stone to the greater victory of Daguerre. Niépce's purpose was to reproduce line-engravings through the agency of light. Over a carefully cleaned piece of glass or silver-plated tablet, he spread a thin layer of "bitumen of Judea," a sort of asphalt. Upon this he laid the engraving, which had been made translucent by oiling or waxing, and exposed the whole to the sunlight for a considerable period of time. The bitumen was affected by the light except in those places which were covered by the black lines of the engraving. Niépce developed this crude print by immersing it in oil of lavendar. This step depended upon the fact that the light so alters the chemical composition of the bitumen in those parts exposed to it that they are insoluble in the oil, whereas the portions that have been protected from its action are removed by the oil. This gave a "negative," so far as the lights and shadows were concerned, but later, by etching the uncovered portions of the metal with acids, Niépce succeeded in obtaining real engraved plates from which reproductions could be made. Herein lies his greatest contribution to the art of

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photography. His method is identical in principle with that employed today.

But to obtain images with the *camera-obscura*, exposures of at least ten hours in the direct sunlight were required, and real photography seemed as far off as ever. Then through the happy circumstance that they both visited at intervals the same Paris dealer in artists' supplies, Niépce and Daguerre became acquainted, and learned that each was striving for the same goal. The result was a partnership formed in 1829, and continued until Niépce's death four years later, and by his son for a much longer period.

Since the pursuit of Niépce's original methods brought no satisfactory results, Daguerre in 1835 began to experiment along new lines. By what fortunate accident he discovered that a silver plate exposed in the dark to the vapor of iodine becomes exceedingly sensitive to light is not known. But that was his starting point. With such plates he was able to reduce the time of exposure to three minutes for outdoor objects, and he could photograph the interior of rooms in thirty minutes. But still the images were faint. He had no satisfactory method of developing them. One evening Daguerre placed one of his exposed silver-iodine plates in a cupboard and left his studio for the night. Imagine his surprise and delight when he discovered the following morning that a picture had been developed upon this plate. Daguerre exposed another plate, and leaving it in the cupboard the next night, obtained a similar result. The cause was a mystery. But he determined to unravel it, for

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in it lay the solution of the problem which had baffled him through so many years of patient effort.

In the cupboard was a variety of chemicals. It seemed clear to Daguerre that some vapor must have produced the welcome change. One by one he tested the substances. At last it became certain that the vapor from a dish of mercury had wrought the effect. Mercury vaporizes only slightly at ordinary temperatures, but possibly this cupboard was unduly warm. However that may be, Daguerre discovered that he could develop an exposed plate by placing it, in the dark, face down over a dish of warmed mercury. Those parts of the plate upon which the rays of light have been focused will absorb the mercury vapor in exact proportion to the intensity of light which has affected them. To fix the image, which consists in dissolving the unaffected portions of silver iodide, he immersed the plate in a bath of sodium thiosulfate, or ordinary photographer's "hypo."

It was a splendid advancement, and the introduction of the new process made a deep impression among scientists and people generally. The pictures were beautiful, and the mystery of it all appealed strongly to the popular fancy. Because no better method was known, the long exposures required, the impossibility of making duplicates, and the somewhat high cost of these pictures did not seem drawbacks then.

Unable to form a company for the development of the new process, Daguerre gave his discovery to the world in return for a pension of six thousand francs a year granted by the French Government. As a

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painter, he had long before won distinction, and his discovery of photography was a fitting triumph to a life-long devotion to the cause of art.

Samuel F. B. Morse, the inventor of the telegraph, learned the process from Daguerre, and upon his return to New York produced, with the assistance of Professor Draper of New York University, the first portrait, about 1840.

An English contemporary of Daguerre, Fox Talbot, developed a process for obtaining prints upon paper instead of silver plates. The subsequent development of the art to the present degree of perfection has been accomplished by many workers.

Alvan G. Clark

Five times was Alvan G. Clark of Cambridgeport, Massachusetts, summoned to grind "a telescope lens more powerful than any in existence," and each time he surpassed the record previously set by his own handiwork. The price received for the Yerkes lens, the largest ever ground, was one hundred and twenty-five thousand dollars. Why so large a sum for shaping a disc of glass but three feet in diameter and two and one-half inches through in the thickest place? And why should the rough blocks of uncut glass cost twenty thousand dollars additional at the Paris works? We shall see.

Alvan Clark was the son of a New England farmer. As a youth be yearned to become an artist. He learned to carve and draw and even paint a little.

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When he had grown to manhood, he entered the Lowell mills as a calico printer. There he worked for nine years, but he could not smother his longing for the life of an artist. He forsook calico printing to become a portrait painter. His success exceeded even his expectations, and he became financially prosperous. One of his sons, while a student at Andover, became interested in the telescope. One day Alvan Clark discovered him at work polishing a metal disc. Upon inquiry he learned that the lad was intending to construct a reflecting telescope. At once the father was interested, and began to study astronomy and mechanics that he might assist his son. Together they built the telescope and began an exploration of the heavens, even as Galileo had done two centuries and more before. The fascination of the study grew with the years, and what was begun as a pastime soon developed into a business which was to make the name of Alvan Clark and Sons known throughout the scientific world.

This was in 1844. Two years later the father and his two sons abandoned every other pursuit to engage in the manufacture of telescopes. The Clarks became known as the most expert lens grinders in the world. Orders came from their own and other lands. And every lens was perfect as human workmanship could make it.

From the casting of the glass to the work of grinding, the production of a big lens presents a task of unparalleled difficulty. It requires the highest skill and the utmost patience. The huge crucible in which

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the glass is melted consists of the purest clays, and is made by specially trained craftsmen. Before receiving the "batch" materials, it is heated gradually, for a week, to a high temperature. Every step of the process is under perfect control and the melting and stirring proceed for days. When the master knows the glass is ready, skilled workmen lift the crucible from the furnace and pour its dazzling molten contents into an iron mold lined with sand. Quickly the mold is covered with an iron plate and lifted into an annealing furnace. There it remains for a month, gradually cooling down to ordinary temperature. This is a critical stage of the process. If the annealing is not properly done, the glass will possess strains and inequalities that render it useless for optical purposes. The glass for the thirty-six-inch refractor at the Lick Observatory was poured twenty times before a satisfactory block was obtained. Do you wonder that even the uncut glass is priceless?

At this point the work of the Clarks began. The rough grinding alone requires several weeks, and at frequent intervals the glass is examined for flaws that may destroy its optical qualities. Then comes the work of the master lens-grinder. After calculating the curvature with a mathematical exactitude, he shapes and polishes the glass with infinite care. Finer and finer must the grinding materials become, and more delicate the operations. Since the finished refractor consists of two parts, a double-convex lens of crown glass and a plano-concave one of flint glass, the work is doubly exacting, for the

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curvatures of the two must agree within one two-hundred-fifty-thousandth of an inch. The two lenses are then centered in a lathe and fitted together for mounting in the telescope. Many months have been consumed in this work, and the skill required for its execution is unexcelled, if indeed it is equaled, in any other art.

Most of the famous refractors have been ground by the Clarks. Some of them are the eighteen-inch glass at Northwestern University, the twenty-six-inch at the United States Naval Observatory, the twenty-four-inch at Harvard University, the thirty-inch at the Alleghany Observatory, Riverview Park, Pennsylvania, the thirty-inch near Petrograd, Russia, the thirty-one-inch at Potsdam, Prussia, the thirty-six-inch at the Lick Observatory, Mount Hamilton, California, and the giant forty-inch, the world's largest, at the Yerkes Observatory of Chicago University.

The Yerkes lens weighs half a ton. It is probable that it will remain for many years the largest refractor. Its purpose is not to magnify, but to gather more light. It has brought into view millions of new stars and has broadened the universe by billions of miles. Since its area is approximately forty thousand times greater than that of the pupil of the eye, it is able to make a star appear forty thousand times brighter than when viewed without its aid.

The work of the Clarks affords an example of the reward of genuine merit. They would never permit the slightest publicity in their behalf. They could not even be persuaded to send samples of their work to

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the Centennial Exposition at Philadelphia in 1876. They never solicited business. It came to them. So superior were the products of their craftsmanship that competition simply did not exist. They loved the art for its own sake and in their devotion to it set standards that will endure.

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CHAPTER XII

JOSEPH HENRY

Among the early scientific discoverers, of whom the Old World boasts so many, America may claim two. They are Benjamin Franklin and Joseph Henry. They worked in the same field, but at different times. One identified the lightning from the thunder-cloud with the electricity of the Leyden jar. The other was a pioneer in those electrical discoveries that have made possible the age of power in which we live. Even in the uncongenial atmosphere of America, away from the great centers of research with their galaxies of famous scientists, Henry made discoveries that won the admiration of his European contemporaries and caused his name to be known on two continents.

Joseph Henry was born at Albany, New York, in 1799. This country was still young. The frontier did not extend far beyond the Ohio Valley and the ridge of the Appalachians. Vast portions of his native state were covered with primeval forests, and, save for the occasional smoke from the white man's cabin, there were no visible signs of the forward march of civilization. In such unhospitable soil science does not thrive. Men are too busy in a first-hand struggle with the obstacles of Nature to devote much time to a consideration of the mysteries of energy and matter.

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But in the somewhat older culture of the East Henry found the incentives for a life of true research.

Henry's parents had come to this country from Scotland and settled in the eastern part of the state in 1775. His father died while Joseph was young, and the boy went to live with his grandmother at Galway, where he remained for several years. At fourteen, he was apprenticed to a silversmith, but his employer soon failed in business and his term of service came to an end. In these youthful days, Henry became interested in theatrical performances and wished to become an actor. He assisted in organizing a debating and amateur theatrical society, for which he wrote one comedy. But just at this time a seemingly trivial event changed the whole course of his life. There fell into his hands a small volume entitled "Lectures on Experimental Philosophy." This turned his mind in an entirely new direction. Henry preserved the book until his death. He later said of it, "It was the first work I ever read with attention. It opened to me a new world of thought and enjoyment; invested things before almost unnoticed with the highest interest; fixed my mind on the study of Nature; and caused me to resolve at the time of reading it that I would immediately commence to devote my life to the acquisition of knowledge."

The stimulus of this book led Henry at once to enter a night school and later the Albany Academy. When his preparation was sufficient, he earned money to continue his studies by teaching school. Imagine this boy, but little older than the pupils whom he

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taught, as master in one of those little red or white schoolhouses that for more than a century have dotted our hills and valleys. In the Academy, his chief interest was in mathematics and physical science. Realizing that a knowledge of higher mathematics is essential to scientific research he set about mastering these branches, including differential calculus, without even the aid of a tutor. Following his academic course, he applied himself to the study of medicine, making both ends meet by tutoring in the family of General Stephen Van Rensselaer. About this time Henry was appointed as engineer to survey a route for a road across New York State. He carried this out with great success. Much of the work was done in the dead of winter, through dense forests and deep snows, among the outposts of the new country. So attractive did this occupation seem to Henry that he was about to accept another engineering position, when his election as Professor of Mathematics and Natural Philosophy in the Albany Academy called him back to a life of scientific research.

Even before this date, 1826, Henry had begun to contribute papers on his experimental work to the "Albany Institute." His first paper was on the "Mechanical Effects of Steam," and accompanied by experiments which would do credit to the demonstrations in our college lecture halls even today. These papers were the results of his own original investigations. That is what research means. Henry attacked problems which were new to him. Always fertile in experimental devices, he had to construct most of his

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apparatus with his own hands. Nothing is more delightful than such work. No one, who has never experienced it, can know the joy of discovery. To be able to proclaim some new truth, to have unravelled some age-old mystery, to have discovered some new process of vast importance to industry, these are the triumphs that are immeasurably more worth-while to the man of science than the accumulation of wealth or the winning of political honors. The scientist never knows that his work will have material value. His one aim is to add to the sum of human knowledge, and, viewing the centuries in retrospect, who will deny that this is the noblest calling among men?

Henry joyfully took up his work in the Albany Academy, where he soon developed into a lecturer and teacher of enthusiasm and rare power. But it was from his experimental researches in the field of electromagnetism that he drew the inspiration for his work. Sturgeon, in England, had just invented the electromagnet. But his invention was a crude affair. He had simply discovered that the magnetic field of a current-bearing conductor is greatly intensified by wrapping the wire loosely about a soft iron core. But neither Sturgeon nor any other European worker at that time had made a magnet of any considerable lifting power. Through the scientific publications from the European capitals Henry kept himself posted upon the discoveries of the past and the new advances, which were constantly being made in this field. He repeated before the Albany Academy all the old demonstrations with apparatus devised by himself,

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much larger and more sensitive than anything ever before used. One of his most beautiful demonstrations was to show the influence of the earth's field upon the magnetic field of a large suspended coil consisting of many turns of fine wire, through which the current from a single cell was passed. In response to the attractive force of the earth's field, the coil immediately set itself at right angles to the magnetic meridian.

But it was as a maker of electromagnets of great lifting power that Henry won his first fame. He was the first to use silk-covered wire for his magnet coils and wooden spools upon which to wind them. The experimenters abroad were quick to adopt these improved methods, and many did so without knowing to whose ingenuity they were indebted. After making a number of small experimental electromagnets, Henry bent a soft iron rod twenty inches long into the familiar horseshoe shape, and wound upon it nine lengths, each sixty feet long, of fine insulated wire. Leaving the ends of the several strands free to be connected as he chose, he obtained numerous combinations with corresponding lifting powers. With this magnet and a single cell containing only half a pint of dilute acid and but one-fifth of a square foot of zinc surface, Henry lifted weights ranging from sixty to six hundred and fifty pounds. This was a marvelous feat for those days. Whence came this mysterious power? How was it possible for the energy developed by one small cell to lift such great weights? The wisest men of Europe did not know at that time. It was only by patient experimentation that the truth would be dis-

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covered, and Henry was fascinated with the task. Using a tiny cell having *plates only one inch square,* he lifted with this magnet a weight of eighty-five pounds. We suspect now that the energy of the cell is simply a directive force, which enables us to tap reservoirs of magnetic force lying within the iron itself. But it is to discoverers of the Henry type that we obtain the basis of such conclusions.

In 1831, Henry constructed a lifting magnet for Yale College, which was made to support a weight of twenty-three hundred pounds, and a little later he made one for his own laboratory, which surpassed that in capacity by more than half a ton. Thus did Henry nearly a century ago do the experimental work which has made possible those giant lifting magnets now so widely used in the iron and steel plants of the world.

Back and forth across his laboratory at the Albany Academy, Henry strung a circuit consisting of a mile of insulated copper wire. At one end he placed a battery and at the other the first electric bell ever devised. It consisted of what Henry called his "Intensity magnet," having a coil of many turns of fine wire and sensitive to a very feeble current, together with a pivoted steel magnet, so arranged as to strike against a stationary office bell. This is identical in principle with the modern polarized bell used in telephone work with an alternating current. Henry produced the same effect by reversing the direction of his current. At each reversal, the pivoted steel magnet struck the bell and gave a signal. In this way Henry

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demonstrated the possibility of the electric transmission of signals before either the English or the American telegraphs had been invented. Indeed, he contributed the decisive factor to the success of both of these inventions. It was a knowledge of Henry's sensitive intensity magnet, that enabled Morse to utilize the weak line current for operating a strong local battery circuit, and thus insure his success. When Henry visited Europe a few years later, he supplied the same information to Sir Charles Wheatstone, and it is said that within two weeks the English telegraph was completed. We see that the patient work of the investigator must precede the practical applications of science.

By 1831 Henry had become known as the foremost experimental scientist of America. As a result, he was called to be Professor of Natural Philosophy at the College of New Jersey, now Princeton University. After a short interruption Henry resumed his original investigations, but he now turned his attention to the new field of electromagnetic induction, or the production of electric currents from magnetic fields of force. This was the field in which Faraday did such distinguished work, but Henry preceded him, and, had he published his results earlier, his would have been the acknowledged honor for these discoveries. As it is, the credit due him is none the less. All of the experiments performed by Faraday were carried out independently by Henry and more. In this work he discovered for the first time the peculiar effect of self-induction, so important a factor in many

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electrical devices. In his later work on induction, Henry's experiments were performed on a much larger scale than those of Faraday. In one instance he induced strong currents in a secondary coil by means of a primary coil and battery placed in an adjoining room.

Henry was one of the first in America to make systematic investigations in meteorology and a study of the electrical disturbances of the aurora borealis. He discovered new phenomena connected with the cohesion of liquids. He did pioneer work on the subject of phosphorescence, and made determinations of the heat radiating power of sunspots. He carried out experiments on the capillary absorption of mercury by a number of metals.

When the Smithsonian Institution was established at Washington through a grant of more than a half million dollars from James Smithson of London, Henry was made the first Secretary, an office which he held until his death in 1878. In shaping the character of this institution during a period of more than thirty years, he served the cause of science as few other men have done.

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CHAPTER XIII

TWO PIONEERS OF ELECTRIC COMMUNICATION

Samuel F. B. Morse

One day in 1832 among the passengers seated about the dinner table of the packet-ship *Sully*, bound from England to America, were Dr. Charles T. Jackson of Boston and Professor Samuel F. B. Morse. As they pulled back their chairs at the close of the meal, Dr. Jackson produced an electromagnet, which he had purchased while in Paris, and began to describe some experiments which he had seen Ampère perform with it. The world had long been waiting for this particular moment. It had waited for Galvani's historic experiment with the frog's legs and Volta's consequent invention of the electric cell. It had waited for Oersted's discovery that a current-bearing conductor possesses a magnetic field and for Sturgeon's invention of the electromagnet. The tools were at hand for the workman who should forge the first instantaneous means of communication.

Morse was tremendously interested in Dr. Jackson's description of the electromagnet. Immediately, he recalled a statement in the textbook of natural philosophy which he had studied many years before at Yale. "If the electric circuit be interrupted at any place the

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fluid will become visible, and when it passes it will leave an impression upon any intermediate body." In after years he said, "This was the crude seed which took root in my mind, and grew into form, and ripened into the invention of the telegraph." There in the cabin of the *Sully* the idea of an electric telegraph took firm hold of Morse's mind. During the tedious voyage Morse busied himself with making sketches of his proposed instruments. Before leaving the ship the scheme was complete — the electromagnet with its armature, the moving tape, and the system of dots and dashes. Morse was enthusiastic. Totally ignorant of any previous work in this field and almost wholly without knowledge of electricity, still he felt that he was on the verge of a great invention. So he was. But he did not realize the years of hardship and bitter disappointments that must precede his final triumph.

It was not as an inventor that Morse had wished his name to go down in history. The ambition of his life was to become an artist. Until he was well past middle-age his energies had been chiefly directed toward this end. He was born at Charlestown, Mass., in 1791, and was educated at Andover and Yale. Even as a lad he had painted in water colors, and while in college he helped to pay his way by painting miniature portraits on ivory, which he sold at five dollars apiece. After graduation, as a pupil of the noted American painter, Washington Allston, Morse sailed with him to England, where he remained for four years. There he made the acquaintance of some of the most notable artists of that day. His work in sculpture won for him

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a gold medal, and a painting of Jupiter some renown. But poverty compelled his return to America.

Although his fame had preceded him and he was cordially welcomed by the cultured society of Boston, no one would buy his paintings. To ward off starvation, he began to paint portraits. Not successful in the North, after three years of hardship, Morse visited an uncle in South Carolina. There he obtained many sittings, and in a few months he had accumulated three thousand dollars. With this evidence of prosperity he married and returned north. But his wife soon died and shortly after, his father and mother. He seemed unable to win either fame or fortune with his brush, and it was upon his return from a second trip to the art galleries of Europe that the incident occurred which was to change the whole course of his life. This was his chance acquaintance with Dr. Jackson and the electromagnet.

Abandoning all thought of becoming a great artist and employing his profession only as a means of gaining a somewhat shabby livelihood, Morse turned with earnestness to the invention of a telegraph. But for several years he made little progress. Without a home, always in financial difficulties, possessing little mechanical skill or scientific knowledge, for more than a decade he led the forlorn life of the typical inventor. One of Morse's private art pupils during those dark days relates the following incident:

"Morse approached me one day and said:

"'Well, Strother, my boy, how are we off for money?'

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"'Why, professor, I am sorry to say I have been disappointed; but I expect a remittance next week.'

"'Next week! I shall be dead by that time.'

"'Dead, sir?'

"'Yes, dead by starvation.'

"'Would ten dollars be of any service?' I hurriedly asked.

"'Ten dollars would save my life,' Morse replied.

"I paid the money, all I had, and we dined together. After we had finished, he said, 'This is my first meal for twenty-four hours.'"

In 1835 Morse was appointed professor of the Literature of Arts and Design at the newly established University of New York. There he began his experiments. But difficulties beset him. His batteries must be made with his own hands. Insulated wire was a curiosity, and he had to wrap with cotton thread the few yards of bare wire that served his purpose. For his electromagnet he obtained from a blacksmith shop a rod of soft iron bent horseshoe shape. His early acquaintance with Mr. L. D. Gale, the professor of chemistry in the university, was of invaluable assistance, especially in the making of batteries. When Morse discovered that the feeble current of his circuit would not operate the armature of the electromagnet, it was Gale who brought to his attention the work in this field of Joseph Henry. Equipped with a knowledge of Henry's intensity magnet, Morse soon invented his relay. This proved a turning point in the actual work of experimentation. The enfeebled line current was made to actuate the weak-spring armature of the

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relay, which in turn made and broke the local circuit, in which were placed a strong battery and the heavy receiver. By 1837 Morse was sending messages through a circuit stretched back and forth across the university laboratory.

One day as Morse was busy over his instruments, a young man, named Alfred Vail, ventured into his laboratory and became deeply interested in what he saw. Morse explained his invention. With prophetic vision young Vail saw the possibilities of telegraph communication, as few were able to do at that early day. He asked for a share in the enterprise and suggested that his father, the master of the Speedwell Iron Works at Morristown, New Jersey, might assist financially in the promotion of the undertaking. No greater good fortune could have come to Morse at that time. He gladly accepted. The elder Vail supplied two thousand dollars for further experimentation and offered his shop for the work. Under the guidance of Morse all the later work of perfecting the first set of instruments and developing the code of signals was done by Vail. Vail was a born mechanic and first and last made many important improvements in telegraph instruments. Within a year from the beginning of the partnership all was completed. Seated at the instruments in the Speedwell foundry, Morse and Vail gave a demonstration in January, 1838, which completely satisfied the latter's father, and the first stage of the invention of the telegraph passed into history.

But the real battle was still ahead. Morse protected his right by patent, and sought the assistance

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of Congress for the building of an experimental line. He exhibited his telegraph in Philadelphia without result and then proceeded to Washington. After much effort he succeeded in interesting the Committee on Commerce of the House of Representatives in his invention. The chairman of the committee even resigned to become a partner in the enterprise. A bill was introduced to appropriate thirty thousand dollars for the building of a telegraph line between Washington and Baltimore. At last Morse seemed to be upon the flood-tide of success.

Instead, however, of remaining in Washington to push his bill through Congress and insure success at home, Morse hastened to Europe to secure his rights in foreign countries. His trip abroad was wholly fruitless, and he returned to America to find Congress indifferent to his bill and a rival claimant to his invention in the person of Dr. Jackson. Morse found himself plunged once more into the depths of poverty and misfortune, which were all the more bitter because of the temporary success which he had enjoyed. He easily proved the falsity of Dr. Jackson's claims, but at the time it seemed exceedingly doubtful that the invention would ever be of value to either claimant. Again Morse was compelled to take private art pupils. While in Paris he had learned the new process of making daguerreotype photographs, and, with Professor Draper of New York University, he opened the first studio of its kind in America.

Still Morse would not give up. He wrote letters to the members of Congress. Whenever his funds would

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permit, he visited Washington. Unceasingly he urged the passage of his bill. Congressmen came to look upon him as a crank. His invention was only a toy anyway, so they said, and if they granted the request of this visionary enthusiast there would be no end to similar demands. But ridicule did not daunt him. Poverty he could endure. And defeat — well, there was no such word in his vocabulary. At last in 1843 his bill was brought up again. It passed the House, and, despite the hostile attitude of many senators, it passed the Senate. But during the evening of its final passage, as Morse sat in the gallery of the Senate chamber, he became convinced that the battle was lost. The opposition seemed too strong and stubborn. Broken in spirit, with his last hope all but shattered, Morse stole out of the building and returned to his boarding house. After buying a ticket to New York and paying his board bill, he had only thirty-seven and a half cents left in the world.

But with the morning came the dawn of better days. While at breakfast he was interrupted by a caller. The daughter of the Commissioner of Patents, Miss Annie G. Ellsworth, had come saying,

"Professor, I have come to congratulate you."

"Congratulate me!" Morse answered in astonishment.

"Why, yes," she replied with enthusiasm, "on the passage of your bill. The Senate last night voted your money, thirty thousand dollars."

The building of the line immediately began. A company had been formed and associated with Morse

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in the enterprise was Ezra Cornell, who was later to found the university that bears his name. Still misfortune seemed to dog Morse's footsteps. He had decided to place the wires underground, but the insulation proved defective and they were forced to abandon the scheme. Two-thirds of the appropriation had been exhausted, and to add to his troubles serious disputes arose among the members of the company. Even yet failure seemed by no means uncertain. At last in desperation, Morse decided, upon the recommendation of Cornell, to string the wires on poles, insulating them from the wood by necks of bottles. The battle was won, and the line was completed without further mishap.

On May 24, 1844, the first anniversary of the passage of the appropriation bill, Morse, sitting at the transmitter in the Supreme Court room at the Capitol, telegraphed to Vail at Baltimore the now famous message, "What hath God wrought?"

Just at that time the Democratic National Convention was in session at Baltimore. Learning that Silas Wright of New York, then in Washington, had been nominated for the vice presidency, Vail telegraphed the news to Morse. Morse carried the message to Wright and received his unqualified refusal of the nomination. Immediately, he telegraphed Wright's refusal to Baltimore, and Vail quickly presented it to the convention. The members of the convention would not believe that the thing had happened and sent a delegation to Washington to interview Wright.

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His confirmation of the messages did much to win public confidence in the new invention.

Morse had won a great triumph, but financial success seemed nearly as far off as ever. The government had refused to buy his patent, and he was compelled to promote it by means of private capital. Organizing the Magnetic Telegraph Company, he raised funds for a line from New York to Philadelphia. Other lines were built. Unscrupulous promoters infringed upon his patent, but in every instance the courts upheld his rights. Still the telegraph business did not prosper. Then in 1856, under the leadership of Hiram Sibley, the Western Union Telegraph Company was organized to combine the various struggling groups into one large system. The venture was a success, and its promoters, including Morse, became wealthy. The leading nations of the world honored Morse with orders and decorations. A number of European sovereigns joined in bestowing upon him a gift of four hundred thousand francs. He died in 1872, but not until he had seen his invention ranked as the leading scientific achievement of his time.

The art of telegraphy has received many contributions from other inventors than Morse. J. B. Stearns of Boston introduced duplex telegraphy in 1858. Multiplex and quadruplex systems were invented by Edison. David Hughes of Kentucky and Professor Henry Rowland of Johns Hopkins University developed rapid printing telegraphs. Elisha Gray devised a harmonic telegraph, which sends twelve messages over a single wire at the same time. The

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multiplex system now in use on the Western Union lines is able to send four messages in each direction simultaneously over the same line and print them in typewritten form ready for distribution. By the recently developed carrier current system of multiplex telegraphy it is now possible to send as many as forty messages over a single wire at the same time. The art of telegraphing pictures has made great progress in recent years, and promises much for the future. Even yet we have not reached the end of invention in the field of wire telegraphy.

In any story of the telegraph it should not be forgotten that Sir Charles Wheatstone invented a telegraph system, which, though inferior to Morse's invention, was used for many years in England.

Sir William Thomson (Lord Kelvin)

When the first two Atlantic cables had been successfully laid, connecting the old world and the new, their ends were joined at Newfoundland and the current from a tiny electric cell consisting of a lady's silver thimble, a bit of zinc, and a few drops of sulfuric acid was sent through them. Even this infinitesimal current traversed the ocean twice and reproduced in the Irish station the signals of the sending operator simultaneously with their transmission. The marvelously delicate recording instrument which made this possible was the mirror galvanometer, invented by Sir William Thomson.

Without the inventions of Sir William Thomson

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submarine telegraphy would have waited for at least a generation. He was born at Belfast, Ireland, in 1824. When eight years of age his father received the appointment as Professor of Mathematics at the University of Glasgow, and the family removed to that city. Two years later, he entered the university as a student, and from the start of his career displayed great interest in science. Together with his older brother he performed many experiments in electricity. After completing his course at Glasgow, William traveled extensively on the Continent, and at seventeen entered Cambridge University. There he pursued advanced courses in mathematics, and made a reputation as an athlete. Literature and music interested him as a pastime, but he chose science for his life work. Upon his graduation from Cambridge, a fellowship yielding a thousand dollars a year permitted him to study for a time in Paris. At twenty-two he became professor of natural philosophy at the University of Glasgow. Since the university had no laboratory at that time, Thomson set about equipping one. In it he carried on investigations in electricity which a few years later were to make him indispensable to one of the most important enterprises of the century.

Chief among that little group of pioneers who, triumphing over seemingly insurmountable obstacles, succeeded in laying the first submarine cables, was Sir William Thomson. But the account of that splendid achievement belongs to another story. Here we are concerned chiefly with those inventions of Thomson

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without which all the efforts of his associates would have come to nothing.

The first cable, laid in 1858, had been ruined through ignorance, on the part of the electrician in charge, of the electrical requirements of cable transmission. The use of too high voltages had destroyed the insulation. Faraday had shown that a long cable with its metallic core, insulating sheath, and the salt water outside acts like a huge Leyden jar, or condenser. The current flowing in the core induces in the water opposing currents, which seriously retard the speed of transmission. In addition, the currents are very weak. This is due to the great length of the conductor and the fact that only small voltages may be employed. Thomson had worked out accurately the law of retardation, and clearly saw that the success of submarine telegraphy must rest upon the delicacy of the recording instrument. His answer to this crucial problem was the *mirror galvanometer.*

The mirror galvanometer consists of a coil of many turns of fine silk-covered wire, in the heart of which is a small air chamber. In this chamber is suspended by a delicate fiber of silk floss a small round mirror. On the back of the mirror are four tiny magnets. The feeble current from the cable is passed through this coil, and its magnetic field acting upon the fields of the tiny magnets causes the mirror to turn one way or the other, depending upon the direction of the current. Focused upon the mirror is a beam of light, which is reflected to a white screen. As the mirror rotates with the changing cable currents, this beam of light

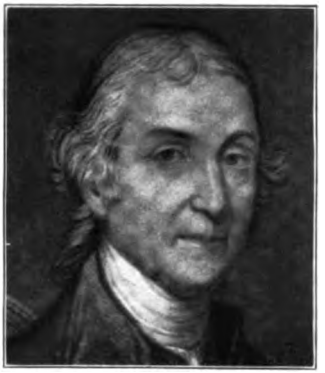
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moves back and forth on the screen. A deflection in one direction means a dash, and in the opposite direction a dot. In cable transmission the current is constantly reversed, thus tracing out the signals of the Morse code. It was with this instrument that the exceedingly feeble currents from the thimble cell were received. Without it the first Atlantic cables would have been a failure.

But if you have ever stood in a cable office, you know that messages are not now received in this manner. Thomson also gave to the telegraph art the *siphon recorder*. Like the mirror galvanometer, such an instrument must be actuated by the weak cable currents. The printing devices used on land lines are impossible here. In this instrument the cable currents pass through a coil of fine wire delicately suspended between the poles of a strong permanent steel magnet. As the coil rotates from the influence of the two fields, its movement is communicated by means of slender filaments to the long arm of a fine glass siphon. The short arm of this siphon dips into a reservoir of ink and the long end moves back and forth across a strip of moving tape. The currents corresponding to the dots and dashes constantly move the coil first in one direction and then the other, thus writing the record on the tape in a characteristic wavy line.

The invention of the selenium cell has made possible an interesting combination of the mirror galvanometer and the siphon recorder. The selenium cell is sensitive to light, that is, electrical resistance is less in the light than it is in the dark. The galvanometer, through

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PRIESTLEY



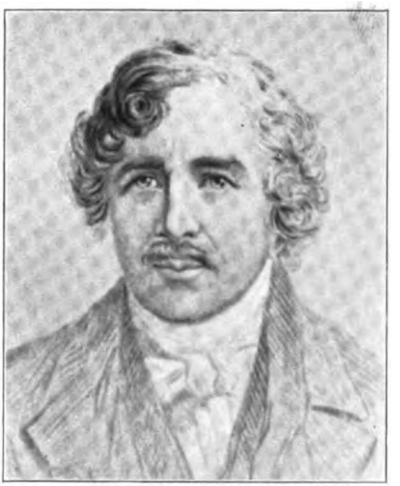
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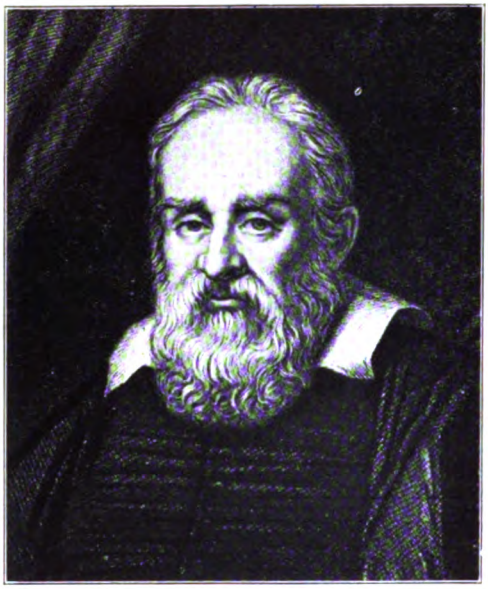


CROMPTON



DAGUERRE

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GALILEO



AGASSIZ



BUNSEN



HELMHOLTZ

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which the cable currents pass, is enclosed together with the selenium cell under a light-tight covering. The instruments are so adjusted that the reflected beam of light is thrown first full on the cell and then completely off from it. The resistance of the cell varies from five thousand ohms when it is fully illuminated to twenty thousand when it is in total darkness. The varying current of this cell actuates the siphon recorder.

But Sir William Thomson was more than an inventor of telegraph devices. He was one of the foremost scientists of the last century and a leader in many fields. He was the inventor of the short-needle compass now so widely used by mariners. He was an early advocate of the doctrine of conservation of energy. He first advanced the idea that the earth is solid to the core and more rigid than steel. He proposed a new theory for the structure of the atom and estimated the size of molecules. He calculated the probable age of the earth's crust and gave an explanation of the continued source of solar energy. Never a follower, he was always in the vanguard of scientific progress. In 1866 he was knighted for his services in laying the Atlantic cable, and in 1892 he was created Baron Kelvin. In 1907 he died, renowned wherever the pursuit of truth engages the interest of men.

The eighteen hundred submarine cables with their quarter of a million of nautical miles and forty thousand cablegrams a day, together with the five millions of miles of land lines and their half million messages each twenty-four hours, bear ceaseless testimony to the worth of his great inventions.

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CHAPTER XIV

CHARLES DARWIN

Not since the days of Copernicus and Galileo has the world been so startled by a new and revolutionary belief as it was by the theory of evolution advanced by Charles Darwin about the middle of the last century. Just as those first of modern astronomers dethroned the earth from its central position in the universe, so did Darwin remove man from his exalted position as a being distinct in his origin from the teeming life of the sea, the beasts of the jungle, and the fowls of the air. The echoes of the conflict, which this new view of creation let loose, have not yet entirely died away.

To understand Darwin and his theory, we must know something of the men who went before him. About a century and a quarter ago an English surveyor, William Smith, began to notice the fossil shells that were preserved in the rocks and soils over which he worked. He noted that these fossils differed from one another, and that they were arranged in regular systems. Wherever a vertical section of rocks was exposed, the fossils were always in the same order. He came to recognize a stratum, or layer, of rock from its fossil population. His keen observation showed him that these fossil remains of extinct animals

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constantly became of a higher and higher type, as he passed from the older to the newer rocks. This pioneer in a new field of scientific investigation also observed that certain types of fossils gradually disappeared and never reappeared in any later rock layers. From these facts Smith came to the conclusion that the earth had been inhabited by successive populations of creatures which had each in its turn become extinct.

The next man to supply links in the chain of evidence was the French anatomist, Baron de Cuvier. One day workmen brought to him some strange looking bones, which they had unearthed in a quarry. Cuvier perceived that these bones came from a species of animal that he had never before seen. Fascinated with this new line of investigation, Cuvier had in a few years accumulated bones from about twenty-five species of animals that he believed were no longer living upon the globe. In his work on Fossils, published a little later, Cuvier described for the first time the mammoth, an extinct type of elephant, which had been found in Siberia so well preserved that the dogs ate its flesh. From these investigations Cuvier proclaimed the view that in past geologic time many species of animals had lived upon the earth which have since become extinct.

But the question immediately arose, how have these species become extinct? The answer seemed simple. Great natural catastrophes had occurred at intervals in world history, completely engulfing the earth and destroying all life upon it. Then after each catastrophe, by special creation new species had appeared.

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Even this moderate view was disturbing to those orthodox individuals who believed that the rocks, fossils, plants, and animals had all been created together in the beginning, just as we know them today. Imagine, then, the consternation that prevailed when Charles Lyell, the great Scotch geologist, showed that the pages of the earth's history, as revealed in its rocks and fossils, gave no evidence of catastrophic changes. He announced the belief that the same slowly acting forces of Nature, which are in operation today, have also wrought the changes of the globe in past geologic ages. He also showed that in many instances there was no sudden change between the fossils of one period and those of the next. Some species lived on into the succeeding epoch. Wonderful, is it not, this unveiling of geologic history extending backward for millions and millions of years? Piecing together the fragmentary pages of the fossil record, the plant and animal life of the past becomes as an open book. Indelibly written in the rocks of the earth, these footprints tell a story second only in its significance to the revelations of the stars. Creation, from being a single grand fiat, becomes the symphony of eternity, a process of marvelous grandeur, continuing from age to age.

That species had gradually changed from lower to higher forms throughout past geologic time could not be doubted. The fossil evidence of the rocks was too conclusive. But how were these changes brought about? Cuvier, even Lyell, and practically all geologists held to the theory of special creation. Yet as

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early as 1809, the year of Darwin's birth, the great French naturalist Lamarck had put forth a theory similar to that of the English founder of evolution two generations later. As already stated, he held that the organs of animals develop and change in response to the influence of their environment, and that as a result new species gradually appear upon the earth.

February 12, 1809, will forever be memorable as the birthday of two of the greatest men of any age, Abraham Lincoln and Charles Darwin. One achieved a political and social revolution, the other wrought a catastrophic change in the intellectual and religious thinking of the race. One broadened the moral horizon of his fellowmen. The other gave a new and nobler meaning to all creation.

Darwin passed his boyhood at Shrewsbury, England, and obtained his early education at Dr. Butler's famous boarding school, where he learned little but Latin and Greek. He afterwards said, "Nothing could have been worse for the development of my mind than Dr. Butler's school." According to his masters, he seems to have been just "a very ordinary boy, rather below the common standard of intellect." In a moment of impatience, his father once said to him, "You care for nothing but shooting, dogs, and rat-catching, and you will be a disgrace to yourself and all your family." While still at Dr. Butler's school he became interested in chemistry and together with his brother set up a home laboratory. Because of these activities, he was nicknamed "Gas."

When only sixteen his father sent him to Edinburgh

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University to study medicine. But Darwin did not seem to have the instincts of a student and wasted much of his time both at Edinburgh and later at Cambridge, where he spent three years, graduating when he was twenty-one. During these days he acquired a fondness for field excursions in botany. He also became an enthusiastic collector of insects, particularly beetles. One day having a beetle in each hand and seeing a third, which he wished to capture, he thrust one of the victims into his mouth. The imprisoned beetle immediately ejected some foul fluid onto Darwin's tongue, and he was forced to spit him out, with the result that he lost two specimens instead of one.

From 1831 to 1836 came the most eventful period of Darwin's life. He was invited by Captain Fitz-Roy to accompany him as naturalist on board the *Beagle* in a voyage around the world. Young Darwin eagerly accepted, and on December 27, 1831, he set sail. The purpose of the expedition was to make a survey of unexplored regions in the lower portions of South America and of certain islands in the Pacific. This was a delightful experience for Darwin. Almost overnight he became a geologist, a botanist, and a zoologist. Wherever the ship landed, he studied the rocks and their fossils. No such systematic examination of fossils had ever before been made. Darwin was much impressed with fossil remains of huge animals covered with armor, like that of the existing armadillos. That closely related species of animals replaced each other, as he moved southward, challenged

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his attention. The animal life on the Galapagos Islands particularly aroused his interest. There he found local species on each island differing but slightly from those on the South American coast. Why should these similarities exist, and how did these modifications arise? Slowly, almost without knowing it, without any previous convictions upon the subject, Darwin was forging the links in a chain of evidence, which nearly a generation later was to give rise to the most epoch-making theory of modern times.

True the evidence was incomplete. There were many missing pages in the record of the rocks, and in some instances but a few lines on each page. Still, in the mind of Darwin, the story began to take form. In these imperishable records of the past, he was able to trace the successive species of animal and vegetable life from the first lowly forms to the highly developed types of the present time. But still the question persisted, how have these changing species come about? The answer was Darwin's theory of "natural selection" and the "survival of the fittest." But he did not rush before the public with his new ideas. He waited twenty-one years, patiently accumulating a mass of evidence, so overwhelming in its completeness that only those who would not listen could doubt the fact of evolution. In 1859 he published his book, "The Origin of the Species."

Among domesticated animals, Darwin had observed the great variety of types that have sprung from a common stock. The mastiff and the terrier have the same parentage. The same is true of the Shetland

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pony, the thoroughbred racer, and the work-horse. The breeder, by selecting certain accidental variations in particular animals, is able to develop a type quite different from the parent form. The preservation and extension of accidental variations through artificial breeding is a matter of common observation. There are many examples of it both in the animal and vegetable worlds. This was the key with which Darwin started in his attempt to read the record of the past written in the fossil dialect of the rocks.

Darwin knew that the individuals of any species always differ slightly from the parent members, and that the offspring transmit these variations to succeeding generations. He knew, too, that in every species many more offspring are produced than can possibly survive. This is due to the fierce struggle for existence, which goes on among organisms. He saw that those organisms will survive which are best adapted to their environment and most able to defend themselves. Thus came the expression, "the survival of the fittest." In this keen competition, those favorable peculiarities in individual specimens, which enable them better to meet this struggle, will be developed from constant use and transmitted to future generations. Thus by a system of natural selection, exactly similar to artificial breeding, and extending over long periods, new species of animals will gradually appear upon the earth. Of course vast stretches of time are required for such infinitely slow processes, but the rate of present geologic changes and the new evidence of radio-activity indicate that the earth is possibly

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billions of years old. Thus did Darwin account for the gradual development of animal life upon this planet. Starting with the invertebrates and passing through the fishes, amphibians, reptiles, birds, and mammals, it culminated in the appearance of man, the present lord of all creation. This was his theory of evolution.

Immediately the storm was on. The theory at once appealed to the intelligence of many enlightened thinkers, but arrayed against it was the majority of his fellowmen. Aside from Darwin himself, Lyell, Thomas Huxley, Herbert Spencer, and later Ernst Haeckel, the new doctrine had no able defenders. But slowly the weight of evidence began to tell. Theologians discovered that the new belief did not destroy their faith after all. When the fierceness of the strife had waned, when the period of bitter denunciation had passed, the truth and beauty of this conception of creation took hold of the minds of men. Seldom has so revolutionary a doctrine made such marked progress in so short a time. At Darwin's death in 1882 the truth of evolution seemed to have been established. Its universal acceptance was bound to come.

The researches of later scientists have brought to light a vast amount of additional evidence in support of evolution. The change from one species to another is not abrupt, as was at first supposed. Wherever it seems to be, we find missing pages in the record of the rocks. The individuals of one species gradually merge through intermediate forms into those of the next. This has been traced especially in the remains

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of the camel and the horse. In the American Museum of Natural History is to be seen a wonderful exhibit of the fossil development of a horse. In a series of thirty specimens we are able to trace the successive changes in the foot and head from the ancestral type to the present form. In many other instances, proof has been piled on proof in bewildering profusion. Not even if he would can one longer doubt the truth of this magnificent epic of creation.

Intermingled with these fossils of extinct animals are flint instruments bearing unmistakable evidences of the handiwork of man. One marvelous bit of evidence consists of the ivory tusk of a mammoth carrying to us from the far distant past the rude but certain portrait of the mammoth himself scratched upon its surface. This is positive evidence of the antiquity of man. Romantic, too, is this indication of the early birth of an artistic temperament in these races of beast-like men. But more than this, fossil remains have been found of prehistoric men. The fossil remains of animals found with the "Heidelberg man" indicates that he lived upon this planet probably three hundred thousand years ago. We may be perfectly sure that even then his ancestors had inhabited the earth for many thousands of years. The relatively high type of animal represented by this man implies vast periods of previous development through the slow processes of natural selection and the survival of the fittest.

In 1871 Darwin published his second volume entitled "The Descent of Man," in which he gave the

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convincing evidences of man's "lowly origin." In the closing words of this great book he says:

"We must, however, acknowledge, as it seems to me, that man with all his noble qualities, with sympathy, which feels for the most debased, with benevolence, which extends not only to other men but to the humblest living creature, with his God-like intellect, which has penetrated into the movements and constitution of the solar system — with all these exalted powers — man still bears in his bodily frame the indelible stamp of his lowly origin."

But we must never forget that evolution does not explain the problem of creation. Evolution is simply the Creator's method of working, as revealed in the record of His handiwork. The problem is only pushed backward, not solved. The time of accomplishment is extended into the past for untold aeons and continued forward into all eternity. Yet back of it all we must put the Divine Purpose of the Creator, working throughout the ages according to a plan, whose outline and meaning we but dimly see. A universe whose laws we are able to understand can be explained only by putting back of it thought and purpose and intelligence. An intelligent world could never proceed from a non-intelligent source. The time will never arrive, as one distingushed scientist said, when "we may escort the Creator to the edges of the universe and bow him out with thanks for his past services."

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CHAPTER XV

TWO MASTERS OF IRON AND STEEL

Iron and steel are symbols of power. Interwoven with their story is the whole fabric of civilization. In the seething fire of the blast furnace we see man's past stretching backward to the gray dawn of antiquity and losing itself in the mists of prehistoric records. If we look closely we may see some savage ancestor of the race bending over his first fire and thereby gaining the first victory in the mastery of Nature. In the heat of his campfire he toughens his implements of warfare and the chase. With its glow he lures wild beasts within his range. Centuries pass, and we descry some primitive descendant raking over the dying embers of his fire and note the awe and superstition with which he discovers shining globules of molten metal. Over and over the discovery is made. His curiosity is at length aroused. He notes the kind of rock upon which his fire was built and deliberately attempts to duplicate the process. After many failures he succeeds, and slowly, painfully from the Age of Stone he passes to the Age of Bronze. Many centuries before the beginnings of Assyrian and Egyptian civilizations we see him come into a mastery of iron. Squatting over a hole in the ground, into which they alternately throw lumps of iron ore and charcoal, two men with a hand

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bellows are blowing the world's first blast furnace into an intense heat. The product is a few pounds of pasty iron. But from that red mass we trace our ever expanding dominion of the earth and the military and political sway of empire.

The use of iron is ancient. It has been found in the pyramids of Egypt, built four thousand years before Christ. Hannibal's soldiers armed with Spanish swords scattered the Roman legions at the battle of Cannae in 216 B.C. The famous blades of Damascus and Toledo tell us of the skill of the early ironmaster. The Britons possessed iron before the Roman conquest. From early times the Scandinavian Vikings used iron in the construction of their ships. Soldiers clothed in steel armor, carrying steel weapons, and mounted on chargers shod with iron were decisive factors in William the Conqueror's victory in 1066.

Still the progress in the metallurgy of this most important of the ores was pitiably slow. The Catalan forge, originating at Catalonia, Spain, nobody knows when, gradually displaced the hole in the ground. About 1340, in the lower Rhine Valley, for the first time in history molten pig iron was produced. The blast furnace grew in size. The "puddling furnace" and the blister steel oven replaced the Catalan forge. Coal and coke were substituted for charcoal as the fuel in smelting. Then came the steam engine, the locomotive, and the steamboat. The world approached an era of vast industrial expansion. But the lack of steel in the prodigious quantities required barred its progress. Yet men did not have long to wait.

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Sir Henry Bessemer

No great invention ever appeared at a more opportune time than the Bessemer Process of making steel. It marked a new epoch. Upon it has depended the romance of modern industry. The railroads that span the continents, the mammoth liners that bridge the seas, the huge sky-scrapers of our cities, the big guns and armor-plate of the proudest navies, the revolutionizing machinery of agriculture and the arts of peace — all these and more have been built from the product of Bessemer's crucible furnace. The wilderness has been subdued, continents have been opened to civilization, the mineral wealth of the earth has been brought to light, and workshops of the world have been transformed. Steel has been a tremendous factor in the development of electric power. It enters into every phase of commercial activity. It has become the symbol of industrial supremacy. Without it nations wither and decay, and for its possession men have fought and died. Steel and yet more steel is the never-ending cry of every workshop in the world.

Sir Henry Bessemer was born at Charlton, England, in 1813, the son of a French inventor of some note. True to his natural heritage, young Bessemer himself displayed a genius for invention. Throughout his long life of eighty-five years he was one of the most prolific inventors of England. When he was only eighteen, Bessemer went to London where his mechanical genius found expression in the work of engraving on steel and modeling in clay. Shortly afterward he invented

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a machine for making a self-canceling stamp, which was adopted by the government, together with a later improvement made by Bessemer. Although this saved a half million dollars a year by preventing the use of fraudulent stamps, he never received any compensation. But Bessemer was not discouraged. He turned to other fields. In a short time he had invented a machine for making figured velvet, and a type-casting device.

One day, soon after coming to London, Bessemer had occasion to buy some bronze powder. To his astonishment he found that it cost one dollar and seventy cents an ounce. "How can this simple metallic powder cost so much?" he asked himself. Hurrying home, he tested some of it in his laboratory and found that it was nothing but brass. For twelve cents he figured that he could buy enough brass to make twenty-seven dollars and twenty-five cents' worth of the powder. Here was a golden opportunity. Why not invent a machine that would cheaply and quickly make this powder by steam power? He determined to try it.

After a thorough investigation and the reading of many old books, he learned the process then in use. It involved much hand labor, which accounted for its price. In feverish haste Bessemer went to work to invent a machine for turning brass into a powder, almost as valuable as gold. His first attempt was a failure. Neither to the eye nor the touch did his product resemble bronze powder. He abandoned the project for a year. Then one day a happy thought

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came to him. Why not examine his powder with the microscope? He did so, and at once the difficulty was revealed. The particles made by his machine were not smooth and flat, but little curled up shavings, rough on one side and without luster. In a short time he made another machine that worked to perfection. He never patented the process because he wished to keep it secret. He assembled the machinery in a small building and placed it in charge of a staff of men who were sworn to secrecy. True to his vision, this process proved to be a real gold mine and for many years it supplied him with ample funds for all his needs, including the costly work of invention.

From then until he was forty, numerous devices claimed his attention. Then came the Crimean War and Bessemer turned his thoughts to projectiles. The War Department laughed at his inventions for firing and rotating elongated shot in smoothbore guns, and would not try them. But in this work Bessemer became convinced that the greatest need of the time was for cheap and abundant steel. He knew nothing of metallurgy, but that did not daunt him. He read everything that he could find on the subject. He visited the iron works of England and saw the methods then in use. His next step was to fit up a shop for experimentation. Seldom has an inventor been more highly favored. Bessemer had a business which with little attention supplied all the money he needed. And he had leisure to experiment. Besides, he was a natural mechanic and could devise and manufacture much of his own apparatus.

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His first object was to make purer iron. He devised and patented a number of improvements in a crucible process for making steel. Then in one of his great moments it occurred to Bessemer that he might burn out the impurities from pig iron with a blast of air. Using a blow torch, and a laboratory crucible holding about ten pounds, he put his theory to the test. Through the mass of molten iron he blew a powerful blast of air. Immediately a shower of sparks rose from the crucible. As they ceased, the flame changed from red to white, then to a faint blue and disappeared. The product was a mass of the purest wrought iron, which forged easily and answered every test. It was not steel, but Bessemer was traveling in the right direction.

He tried the process on a larger scale, but the results were not satisfactory. Exhausted by the strain of nearly two years of constant work, Bessemer became ill. While recovering from his illness, he conceived the idea of a large crucible having a perforated bottom, through which to blow the air, and mounted on trunions so that it might be rotated into any desired position. As soon as he was able, Bessemer built such a crucible. To the pipe leading to the perforated bottom he connected a powerful engine and blower. He started the blast and then ordered a half ton of molten pig iron to be poured in. To the amazement of every one there was a tremendous roar and a volcanic-like torrent of sparks. The cover of the furnace melted and disappeared into the crucible. But soon the tempest had passed. The sparks ceased and the

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flame practically disappeared. The product proved to be a good quality of steel. In a few minutes Bessemer had produced steel equal to that which by the older method required weeks of patient labor. A new milestone had been passed. Yet bitter disappointment and many months of further experimentation awaited the inventor.

Bessemer immediately patented his process and described it before the assembled ironmasters of England. The announcement created great enthusiasm, and a number of them paid Bessemer large royalties for the right to make steel by this new method. But every trial turned out poorly. Even Bessemer failed in his second attempt. Here was a deep mystery, which must be solved. Something was wrong but no one knew what it was. From being borne on the wings of triumph Bessemer suddenly found himself back to earth and almost buried beneath an avalanche of ridicule and criticism. This was in 1856.

Confident of ultimate success, Bessemer patiently went to work to locate the trouble. He found it. The iron with which his first experiments had been made was by accident free from phosphorus. The presence of phosphorus, even in small quantities, will ruin steel. It makes it brittle. Analysis showed that the iron used in all the other trials had contained phosphorus, as did most of the iron produced from British ores. Bessemer then imported phosphorus-free iron from Sweden and soon brought his process to a final success. To give to the steel the requisite quantity of carbon, without which iron is not steel, a small amount of an

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alloy of iron, manganese, and carbon was added at the end of the blow. This vitally important factor in the success of the process was probably due to a fellow-countryman named Robert Mushet. In recognition of Mushet's claims, Bessemer pensioned him in later years. Something more than a decade after, Messers. Thomas and Gilchrist adapted the Bessemer converter to the use of iron from phosphorus ores.

Bessemer's second announcement of his process was received with open skepticism. No one would have anything to do with it. The ironmasters thought they had been fooled once and they would have no more dealings with him. Determined to convince his critics, Bessemer obtained the financial assistance of friends and built his own works at Sheffield. He was soon in open competition with his " enemies " and selling steel of the highest quality at one hundred dollars a ton cheaper than the prevailing market price. That was an argument which could not be met. The superiority of his process was reluctantly acknowledged and Bessemer speedily became the leading steel maker of the British Isles. Furthermore the very men who had heaped ridicule upon him were compelled to license the use of his patents or face financial ruin. Within ten years his revenue from this source was a half million annually and in fourteen years his great works at Sheffield had yielded eigthy-one times their original cost. His fortune rapidly grew until he was many times a millionaire. The story of great inventions affords no more notable example of the wresting of

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victory from seeming defeat than Bessemer's mastery of the conversion of iron into steel.

Yet Bessemer continued to invent. Many of his hundred and twenty patents were taken out after this time. He was honored with a fellowship in the Royal Society and tardily knighted by his country. He lived until the very close of the century, dying in 1898, rich in the esteem of his fellowmen and conscious of having contributed to the industrial growth of the world as few other men have done.

Andrew Carnegie

Andrew Carnegie was neither an inventor nor a master of science. But few men have been more successful in adapting a great invention to the needs of his time than was Andrew Carnegie in seizing upon the Bessemer Process and using it for the expansion of American and world industry. His career in the field of applied invention and the colossal scale upon which he launched his projects ushered in the day of big business. Of remarkable vision and boundless enthusiasm he was the typical product of a new country of measureless natural wealth and unlimited resources. He lived and was a chief factor in the heyday of American industrial triumphs. He belongs to that romantic and picturesque period of empire-building which saw this country grow from a provincial people to a mighty nation. The products of his iron and steel mills provided in inexhaustible quantities the raw materials for this unparalleled expansion. Bold,

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restless as one of his own fiery furnaces, a pioneer in big ideas, it would be difficult to picture the progress of the last half century without the achievements of this first of the steel kings.

Andrew Carnegie was born at Dunfermline, Scotland, in 1835, and when thirteen emigrated to Pittsburgh with his parents. His father was a weaver and Andrew soon found work as a bobbin-boy in a cotton mill at a dollar and twenty cents a week. At the end of a year he became a stoker of a furnace and the operator of a small engine. Soon he got a job as messenger boy in a telegraph office. Here he learned telegraphy and was promoted to the rank of operator at three hundred dollars a year. Having attracted the attention of Colonel Thomas A. Scott, Pittsburgh superintendent of the Pennsylvania Railroad, young Carnegie at nineteen became a railroad operator with a salary of four hundred and twenty dollars a year. One day in the absence of Colonel Scott, to clear a tie-up in traffic, Carnegie sent out a dozen telegrams, each signed "Thomas A. Scott." For this bold piece of strategy he was made private secretary of the superintendent.

But Carnegie did not long remain an employee. His father died and he had become the head of the family. Mortgaging their home for five hundred dollars and borrowing a hundred more from Colonel Scott, Carnegie bought ten shares of Adams Express Company stock. Each month he received a dividend of six dollars. Thus he had become a capitalist. As fast as he could save money he bought more stock. At

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twenty-eight he succeeded Colonel Scott as superintendent of the road. He bought a block of stock in an oil company, which soon yielded him a thousand dollars, and eventually much more. His capital shortly grew to several thousands.

On May 2, 1864, Carnegie entered the iron business, from which he was to emerge nearly forty years later chief among the steel kings of America. Investing eight thousand nine hundred and twenty-five dollars, he bought a sixth interest in the Iron City Forge Company. In four years he had paid for his stock out of its profits. At this time he purchased for seventy-three thousand six hundred dollars a controlling interest in the company. The wonderful expansion in railroad building between 1866 and 1872 brought prosperity. Carnegie supplied the business genius of the company and brought to it a continuous stream of profitable contracts. In 1872 a bond-selling trip to Europe for the Pennsylvania Railroad netted him two hundred and fifty thousand dollars in commissions. A similar venture soon brought him seventy-five thousand more. He was then a capitalist of standing.

On a trip to England at about this time Carnegie chanced to see the spectacle of a Bessemer converter in full blast. He saw this huge monster swallow fifteen tons of molten pig iron and in as many minutes blow it into white hot steel. The volcanic fury of the action and the magic of the process fascinated him. The whole operation seemed little short of miraculous. Henceforth, steel became the watchword of his career.

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As quickly as the ocean liners of that day would carry him, he returned to Pittsburgh. There he organized the Edgar Thomson Steel Works and launched the Bessemer Process in America upon a large scale. It is true that William Kelly of Pittsburgh had invented a converter similar to Bessemer's and had made steel by this process at about the same time that Bessemer did. But the first real introduction of the process in this country began with Andrew Carnegie.

With the flood of steel came a flood of gold. The profits of the Carnegie Steel Company for 1876 were forty-two per cent. And so they continued. But these huge profits were not paid out in dividends. They were put into improvements and the purchase of coal and ore lands. By 1881 Carnegie had acquired a controlling interest in the company, and the profits for the next eight years averaged forty per cent a year. He took into partnership Henry C. Frick, the coke king of the steel industry, and purchased the steel plants at Homestead and Duquesne. He built the Union Railway and thus transformed his scattered system into a complete industrial unit. By 1892 his company had become a twenty-five million dollar concern. In 1897, Carnegie acquired possession of vast supplies of ore in the Lake Superior region, the richest ore field in the world. Three years later he established a line of seventeen steamships to bring his ore to Conneaut, Ohio, and secured control of the Pittsburgh, Bessemer, and Lake Erie Railroad to carry it to his mills. He was now independent. His

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vast system had become a self-contained unit. During the years 1898 and 1899 the profits of the company exceeded seventy million dollars.

Carnegie had early found that machinery is cheaper than human labor and absolutely essential to big-scale production. He discovered that he could profitably invest one thousand dollars to replace the services of a single man. Therefore he placed the industry upon a machine basis. Electric and steam shovels, cranes, rollers, shears, stamping machines, and furnace-charging apparatus, besides numerous other labor-saving devices had reduced the man-power of the industry to a minimum. In this respect it differs from the practice in any other country. Nowhere on its thousand-mile-journey from the mine to the mill nor in the later process of smelting and manufacture is the steel touched with human hands. Machine-handled at every point, it may be truly said that "steel is not made with hands."

But Carnegie was a producer of raw steel and not a manufacturer of finished products. When in 1900 the large manufacturers of finished steel threatened to produce their own raw material and cut off Carnegie's market, the "Caesar of steel" began the erection at Conneaut, Ohio, of the largest finishing plant in America. His position was impregnable. Possessed of vast supplies of ore and coal, the largest mills, steamships and railroad lines, besides unlimited capital, he was the acknowledged dictator of the situation. His opponents could not hope to compete with this mighty organization. Consternation spread through

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their camp. To save them and the Wall Street owners of steel stocks, the United States Steel Corporation was organized to buy Carnegie out and control the industry. He sold for nearly *half a billion dollars*. The bobbin boy of the cotton mill had become one of the two or three richest men of the world.

The later life of Carnegie, his vast benevolences, his founding of libraries, are too well known to need repeating here. Self educated, widely traveled, a polished gentleman of culture, yet acquainted with the sterner side of life, he was equally at home in the king's palace and the poor man's cottage. Andrew Carnegie will long be remembered as a picturesque figure of a romantic period.

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CHAPTER XVI

LOUIS PASTEUR

In 1885 in a Paris hospital one might have seen an old man keeping anxious watch over the life of a peasant lad. Eagerly he observed every symptom. For two weeks he had scarcely eaten or slept. Life was precious to him, and this was to be his crowning achievement in snatching men from death. Would the crucial test of this new treatment fail? Or would the dreaded malady of rabies come under the control of preventive medicine, even as anthrax and other contagious diseases had done? He had applied his new-found vaccine to the young victim of a mad dog's bite. This man, old before his time in the service of his country, was Louis Pasteur, the father of the germ theory of disease, and acclaimed by the populace of France as its most illustrious citizen. The lad lived, and thousands in every part of the world have since owed their lives to the Pasteur treatment.

As a boy Pasteur possessed considerable talent for drawing, was exceedingly conscientious, and never guessed at conclusions. Here were the very characteristics that in later years were to make him the foremost scientist of France. That dogged persistence, that clearness of judgment, that keenness of vision, which led him from conquest to conquest, were all to

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be seen in the boy. The father, a soldier of the Third Regiment under the first Napoleon, was his constant companion, guarding him from the temptations of youth and firing him with an unquenchable love of country. Pasteur was born at Dôle, in 1822. When sixteen, his parents at some sacrifice sent him to a school in Paris, but extreme homesickness soon brought him back. A little later he attended colleges at Arbois and at Besançon, from which he received the degrees of bachelor of letters and bachelor of science. Just as Berzelius had been set down as mediocre in chemistry, so was Pasteur. In 1843 he entered the École Normale at Paris. It was there that he formed the determination to devote his life to science. At the Sorbonne he came under the influence of Jean Baptiste Dumas, the foremost scientist of the French capital. The charm and eloquence of Dumas' lectures in chemistry captivated the impressionable mind of young Pasteur. From this he gained an undying enthusiasm for research, and the spirit that made him cry out that the days were too short and the nights too long.

During these days Pasteur acquired his deep interest in the rare beauty of crystal forms. His first important work was to be in this field, and curiously enough it was to be assisted by the microscope, an instrument which became his life-long guide to discoveries. Having reviewed the pioneer work of Mitscherlich on the microscopic study of crystals, Pasteur began a critical examination of the salts of tartaric and racemic acids. The crystallized sodium

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and ammonium salts of these two acids were identical in every respect, except that the tartrate deviated the plane of a beam of light passed through it to the right, while the racemate had no effect upon it. This was apparently a trivial difference. A number of Pasteur's friends told him that it was not worth serious attention. But the young scientist could not rest until the cause had been discovered. And, little knowing it, he was to open a vast new field of chemical research.

Under the microscope Pasteur observed that these crystals were not symmetrical. The tartrate crystals had facets, or tiny faces, on one side. So did the racemate crystals. But — and here was the difference — the facets were all on the right-hand side in the tartrate crystals, while in the racemate crystals they were on both sides. Patiently Pasteur separated the crystals from the racemate salt into two piles. Those having the facets on the right-hand side were identical with the tartrate and now rotated the beam of light to the right just as the tartrate did. Those having the facets on the left-hand side rotated the beam of light to the left. Rushing into the corridor, Pasteur embraced the first passer-by and pulled him into the laboratory that he might explain to him his discovery. Thus is it often in the first moments of a great triumph. Pasteur soon learned how to transform tartaric acid into racemic acid, and by these researches laid the foundation for the important work of Van't Hoff and Le Bel a generation later on the structure of the molecule of carbon compounds. For Pasteur

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himself they won instant recognition and the red ribbon of the Legion of Honor.

Pasteur's first professorship was that of physics on the faculty of Dijon, which he soon left for the chair of chemistry at Strasburg. In 1854 he became dean of the Faculty of Sciences at Lille. Three years later he returned to the École Normale at Paris, with which he was associated for many years. Into the laboratory and lecture hall he brought the enthusiasm of his own keen interest, and inspired his students with the spirit and love of science. He was a marvelous teacher. Hundreds from his own and other lands flocked to his lectures. He was a consummate master of the scientific method of observation and with it he united an unquenchable thirst for truth. And yet he demanded that all scientific discovery have practical application.

At Lille Pasteur began those researches on microorganisms that were to lead him step by step to the conquest of infectious and contagious diseases. Located in the midst of the great distilleries of northern France, he turned to the study of fermented liquors. Wine frequently "went bad." It became sour. What was the cause? Could it be prevented? These were the questions asked him by the wine-makers of France. Fermentation had been known from the earliest times, and chemists thought they understood its cause. Berzelius and Liebig, who dominated the scientific thinking of Europe, had taught that the fermentation of sugar to form alcohol and carbon dioxide was a purely mechanical process. Pasteur determined to go to the bottom of this question. With his ever-present

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microscope, he studied every step of the process. Gradually he became convinced that fermentation is the result of a vital change associated with the life of the yeast cells, which are always present in the production of alcohol. He proceeded to prove it. In a series of experiments, now classic, Pasteur demonstrated that alcoholic fermentation can never be set up in fermentable juices which have been sterilized by heating and afterward protected from the germ-laden dust of the air. This precipitated a battle royal with Liebig, but the facts were against the German autocrat, and he was compelled to surrender. Pasteur did more than this. He showed that every kind of fermentation, as well as alcoholic, is due to a specific micro-organism. The souring of wine he traced to an organism which develops in the wine upon long standing. To destroy it, he introduced the practice, known everywhere now as pasteurization, by which he heated the wine at a definite temperature for several minutes, out of contact with the air. The wine might then be kept in sterilized casks indefinitely, if contamination from the air were prevented. We now know that fermentation is caused by inorganic principles called enzymes which are secreted by living organisms. Still Pasteur was essentially correct.

Later Pasteur was called upon to perform a similar service for the brewing industry. Just as wine soured, beer became bitter. Pasteurization did not solve the problem. Beer that had been heated soon became bitter again. This led Pasteur to set his "culture mediums" for catching and growing bacteria in the

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breweries themselves, especially near dusty walls and rafters. He soon found them infected with the same germs that were in the bitter beer. But beer that had been heated and sealed from the dust-laden air with sterilized cotton plugs remained sweet. There was the answer. He taught the brewers to wash down the brewery walls and to keep their product free from dust. The cause was removed and bitter beer became a thing of the past.

These studies in microörganisms led Pasteur to ask whether the universal belief in spontaneous generation was not a scientific fiction. Again he determined to answer the question by a series of experiments that should leave no doubt. According to the current belief, organic matter in a state of putrefaction was transformed into living organisms. At the end of a year of patient work, Pasteur had his answer. In his memorable lecture delivered at the Sorbonne on April 7, 1864, he vanquished the ghost of spontaneous generation for all time. After detailing his exhaustive experiments, showing conclusively that the source of these organisms is the dust of the air, Pasteur produced a flask of putrescible matter, which had been sterilized and sealed to prevent the entrance of dust. There was the liquid after several months, pure and limpid as distilled water, because, as Pasteur then stated, "I have kept it from the only thing that man can produce, from the germs that float in the air, from Life, for Life is a germ, and a germ is Life. Never will the doctrine of spontaneous generation recover from the mortal blow of this simple experiment."

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Early in 1865 Pasteur was called upon by Dumas to go to the south of France and study the silk-worm disease, which was threatening to destroy the industry, and an annual revenue of one hundred million francs. Pasteur knew nothing of silk worms and he disliked to leave his work in Paris, but his patriotism would not permit him to refuse. For nearly six years he battled with this obscure problem. In the midst of it he was stricken with partial paralysis and for days lay at death's door. To a friend at his bedside, he said, "I am sorry to die; I should have liked to render further services to my country." He did not know that his greatest services were yet to come. He rallied and returned to his work. Following out his theory of microörganisms, he found the germ that killed the silk worms and prescribed the remedy. It was a Herculean task and was achieved only after many bitter discouragements and a prodigious amount of work. No soldier on the field of battle ever served his country with a finer sense of devotion or won a more glorious triumph than did Pasteur in this research.

In the Franco-Prussian War, he tried to enlist and had to be reminded that a paralytic could not perform the duties of a soldier. But he gave his son, and at the close of the war, he turned with passionate devotion to the cause of science, in the hope that he might thereby assist in retrieving the fortunes of his country. He had been elected to the Academy of Sciences, and in 1873 he was elected to the Academy of Medicine. Gradually a great thought had been taking shape in his mind. His work on microörganisms led him to

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ask why the diseases of humankind might not also be caused by germs floating in the air, and carried from individual to individual. No question more momentous to the welfare and happiness of the race has ever been asked. It was a lightning flash of genius leaping from the trained imagination of this great scientist. To the solution of the problem Pasteur applied himself with that breadth of knowledge, that rare insight, that skill which a quarter of a century of scientific achievement had given to him. His goal was now preventive medicine. "Perhaps," he said, "I can save more lives than were lost in the Franco-Prussian War."

Surgeons looked on with impatient amazement when Pasteur went into the hospitals and snatching the instruments from their hands passed them through the sterilizing flame. It had never been done. Why must they submit to the faddish notion of this crazy old paralytic? But Pasteur would not be thrust aside. The frightful loss of life in the French hospitals was needless. Of that he felt certain, and he was determined that it must cease. In 1871 he had cried out against the enormous sacrifice of life from gangrene, which he believed was due to air-borne germs. He forced the use of sterilized bandages and with all the energy of his soul sought to overcome the skepticism of the medical profession and to gain their acceptance of his revolutionizing ideas. More than a decade before, Lord Lister, the real father of antiseptic surgery, had brought these methods to a triumph across the Channel. For the first time he used drugs to cleanse

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a wound and keep it free from the entrance of infectious germs. Now Pasteur, with little, if any, knowledge of Lister and his work won an even greater victory on the Continent.

In 1877 Pasteur began his investigation of anthrax, that insidious disease which each year took frightful toll of the cattle, horses, pigs, and sheep of France. From examination of the blood of animals that had died of this disease, he found the germ which caused it. Familiar with the methods of inoculating against small-pox, Pasteur sought to apply similar means to the conquest of anthrax. His first triumph was a by-product of this work. He developed a virus, which, injected into the blood of a fowl, rendered it immune from the germ disease known as "chicken cholera." This was the first step, and Pasteur felt that he was on the right path. He next discovered that the anthrax germ lived and multiplied in the blood of sheep, and other domestic animals, but that it would not cause the disease in fowls. Pasteur sought the reason and found it in that the blood of fowls is four degrees warmer than that of the other animals. Therefore, by cultivating this germ at temperatures slightly above that at which it thrives best, he obtained a vaccine, which by inoculation would produce the disease in a mild form and render the animal immune from further attack.

In 1881 Pasteur laid his discovery before his associates in the Academy of Sciences. Immediately it was put to test in a most dramatic way. The president of an agricultural society offered forty-eight sheep,

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two goats, and ten cattle for demonstration purposes. Pasteur accepted. On May 5th, half of these were inoculated with the preventive vaccine. Two weeks later these same ones were inoculated again with the preventive vaccine. Then on the thirty-first of the month all sixty of the animals were inoculated with the virulent, disease-producing microbes of anthrax. Two days later a vast crowd of veterinary surgeons, newspaper correspondents, and farmers gathered to witness the closing act of the experiment. What they saw was a scene which, as Pasteur said, "amazed the assembly." Each and everyone of the unprotected animals was either dead or dying, while the thirty that had been inoculated moved about with every appearance of perfect health. The scourge of anthrax was no longer to be dreaded, and its passing marked the beginning of a new era in preventive medicine.

Pasteur had demonstrated that disease is caused by germs. Following up these investigations, he achieved the crowning triumph of his life. In 1885 he produced a vaccine which robbed of its terrors that most fatal of maladies, hydrophobia, the disease resulting from the bite of a mad dog. He obtained this vaccine from the spinal cord of a guinea-pig which he had inoculated with the virus of hydrophobia. Pasteur found the spinal cord rich in these germs, and also discovered that they gradually lost their virulent power upon exposure to the air. By varying the length of exposure he obtained the preventive virus in differing degrees of strength, from very violent to very weak.

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The fame of Pasteur's work had spread abroad. Just as success smiled upon him in this last great achievement, he received word from the mayor of a country town that a shepherd boy had been bitten by a mad dog. Without immediate aid death would be certain. Pasteur sent for the boy. He had never tried his vaccine on a human being. But, with the faith of one who knows his ground, Pasteur applied his remedy. He began with the mildest vaccine and inoculated with a stronger one each day until at the end of fourteen days he used the virus in its most powerful form. These were anxious days for the aged scientist. Would the treatment prove a success? Would this young life be saved? Had he led his fellowmen past one more milestone in the conquest of human disease? The complete recovery of the lad gave the answers.

But more than this, the pioneer work of Pasteur inspired the more recent achievements of a host of others in combating tetanus, cholera, diphtheria, typhoid, yellow fever, malaria, bubonic plague, leprosy, pneumonia, and many other ills. It founded the new branch of medicine known as serum-therapy, by which antitoxins are developed in the blood of animals, with which to inoculate against disease.

On the sixty-fourth anniversary of his birth Pasteur was awarded the Jean Reynard Prize for his conquest of rabies, and at that same time a subscription list was opened for the building of the Pasteur Institute. Contributions came from every part of the world, and

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it was opened two years later. Here during the last seven years of his life, Pasteur, with an able corps of assistants, organized the wonderful work in bacteriology now carried on there. In a crypt at its base he rests from his labors.

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CHAPTER XVII

LOUIS AGASSIZ

"I cannot afford to waste my time in making money." Thus wrote Louis Agassiz, when tempted by a flattering financial offer to forsake some important investigations in the field of zoology. And throughout his life of unwearied activity in the interest of science the distinguished Swiss naturalist and American by adoption valued money only as it served to advance the cause nearest his heart. Louis Agassiz was a born naturalist. His heart beat in sympathy with that of every living creature. The very fact of existence established in his mind the imperishable worth of every form of life, however lowly. His bewitching power lured from their haunts all living things. They answered his call as did the children the music of the Pied Piper of Hamelin. And he loved the rocks with an equal fervor, possibly, because they revealed in their fossils the story of animal life in past geologic time. But above all he was a teacher. "Louis Agassiz, Teacher" is the description given of himself in his will.

Agassiz was born at Motier, Switzerland, in 1807, the son of a Protestant clergyman. It was a beautiful spot in which to spend his childhood. Below the little village gleam the blue waters of lake Morat and in the

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distance the Bernese Alps lift their snow-capped summits. On every side lie green hills and pleasant valleys. With such surroundings it is no wonder he became a naturalist. From earliest boyhood his chief delight was to roam the fields and bring home new specimens of birds and animals and insects. Lake Morat itself afforded a never-ending source of pleasure to him and his brother Auguste. The study of the fish was a special delight. He learned the haunts and habits of every species. So skillful was he in swimming and diving that he could catch them in his hands without the aid of hook and line. He also became an expert mountain climber. The glaciers fascinated him. Always in perfect health, he gloried in every form of outdoor activity. In summer there was boating, and in winter skating and skiing. The days passed like a song.

Not until he was ten years old did Agassiz attend a public school. His early education was obtained at home. Then with his brother Auguste he spent four years at a boys' school in the nearby town of Bienne. But Louis was a genuine boy, and the long vacations brought him his happiest days. In them he could indulge his love for all outdoors. His early ambition was to become an author. At fourteen he wrote his father, " I wish to advance in the sciences. I have resolved to become a man of letters." And both a scientist and a writer he became.

After leaving Bienne, he attended the Academy of Lausanne for two years and then entered the medical school at Zurich, for it had been decided he should

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become a physician. His father, always sympathetic with his son's desires, felt that the study of medicine would afford Louis an opportunity to follow out his scientific inclinations and at the same time make his living. Agassiz was accurate, painstaking, and thorough. At Lausanne, for the first time, he had access to a natural history collection, and there he found congenial friends, also interested in his favorite pastime. At Zurich he began the study of birds and eagerly took up the sciences of zoology and geology.

After two years at Zurich, Agassiz entered the University of Heidelberg, where he passed four of the happiest and most important years of his life. Here he formed lasting friendships; particularly that with Alexander Braun, whose sister he married a few years later. With a number of companions he formed a club for the study of science and philosophy. So popular did it become that students and even professors attended the meetings. Agassiz's room became a museum. Specimens of every sort, both living and dead, abounded. His vacations were spent with his comrades in long rambles over southern Germany and excursions among the Alps. From Heidelberg, Agassiz went to the University of Munich where he received degrees as doctor of philosophy and doctor of medicine. But medicine had lost its appeal and he returned to the field of his first choice, leaving Munich "devoted heart and soul to science."

In 1829, Agassiz published his first important work. It was a treatise on the fresh-water fishes of Brazil, prepared from a collection made by a noted scientist

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who had died before he had been able to make the report himself. From Munich he went to Paris, where he made lasting friendships with Cuvier, the great French anatomist, and Alexander von Humboldt, the naturalist and a foremost scientist of Europe. Encouraged by the cordial reception with which his book on " Brazilian Fishes " had met, Agassiz determined to prepare a history of the fresh-water fishes of Central Europe, including the fossil as well as the living forms. It was the most tremendous research of its kind that had ever been undertaken. But amid a host of other duties, he carried it to completion, publishing the five large volumes, recording his work, at intervals from 1833 to 1843. In them he developed the method of classifying fish according to the character of their scales, a method which has been employed even down to the present day.

Poverty soon compelled Agassiz to abandon the congenial scientific atmosphere of the French capital. He left to accept the chair of natural history in the college of Neuchâtel. There he became the life of the college and the most influential citizen of the town. Gathering about him a group of earnest students interested in the study of natural science, he began that career which was to rank him as one of the world's masters in the difficult art of imparting knowledge to others. While there, he carried out his now classic investigations of glacier phenomena. After six years spent in the study of glacial deposits, he was able to give invincible proof to the scientific world of the existence in past geologic time of vast ice-sheets in

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places now covered with smiling landscapes and bathed in a temperate climate. In gathering these data, he lived for a whole summer upon the surface of an Alpine glacier. Throughout the rest of his life he was constantly adding to his overwhelming mass of proof. It was his most important contribution to the science of geology. As Agassiz said, "The idea that such phenomena were not restricted to regions where glaciers now are found, but that traces of glacial action could be seen over enormous tracts of the earth's surface, perhaps including regions in the tropics, and that in countries now temperate there might be discovered, not only the remains of tropical fauna and flora, but also distinct indications of a period of arctic cold — this was as new as startling."

Honors came to him. He was offered professorships in the universities of Geneva and Lausanne, and the Geographical Society of London awarded him the Wollaston Medal. At this same time the King of Prussia granted him fifteen thousand francs to be used in travel in the interest of science, and the Lowell Institute of Boston invited him to visit the United States. Agassiz gladly accepted both, and in the autumn of 1846 sailed for America.

Two courses of lectures delivered at the Lowell Institute and later in the leading cities of the East soon made him the most popular lecturer of the country. Agassiz possessed a peculiar charm of manner, a lucidity of statement, and a sympathetic understanding of his audiences which captured their hearts. His cleverness at artistic blackboard illustra-

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tion of his discourses was a tremendous help. In 1848, he accepted the chair of zoology and geology at Harvard University and decided to remain permanently in the new country. As the years passed, he came to love America and her people. And the personal magnetism of Agassiz, together with his rare qualities of heart and mind, drew friends from every walk of life. An acquaintance states that " Everybody sought his society, and no one could stand before his words and his smile." Shortly after leaving his native land, his wife died. Several years later he married Elizabeth Cabot Cary of Boston, having in the meantime brought his family to America. In 1861, he became an American citizen.

Although he had left his collections in the Old World, he immediately began to accumulate new ones. The rock formations and the animal life of the new country opened up to him a veritable paradise. Every stone and every insect had a story, and nothing escaped the penetrating power of his observation. In 1859, he founded the Museum of Comparative Zoology at Harvard, which is today his greatest memorial. To enrich it with rare and varied specimens from every part of the world became a chief object of his vigorous manhood and his declining years. In the interest of this work he conducted expeditions to Lake Superior, the Florida reefs, the Mississippi River, Brazil, and along both coasts of the South American Continent. His powers of persuasion brought financial assistance in abundance both from the State Legislature and private sources.

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Just as in his youth, he was always busy and always happy. On one occasion he exclaimed "Time! my only trouble is that I have not time enough for my work. I cannot understand why anybody should be idle; much less can I understand why anybody should be oppressed by having time hang on his hands. There is never a moment, except when I am asleep, that I am not joyfully occupied. Please give to me the hours which you say are a bore to you, and I will receive them as the most precious of presents. For my part, I wish the day would never come to an end."

Starting life as an atheist, his study of Nature led him step by step to a fervent belief in a divine purpose and intelligence back of the universe. But he could never bring himself to accept Darwin's theory of evolution. To him this doctrine seemed to substitute a soulless energy for the Divine Being. Yet it is difficult to understand how a man of his intelligence and extensive knowledge of the geological life of the past should have failed to recognize that evolution is simply the Creator's method of working. But it was his very humanity, his kindred feeling for every living thing, that led him to reject this new view of creation. Although his antagonisms were often strong, they never prevented him from seeing the reason in his opponent's position. In his differences with contemporary men of science he was always fair and courteous. As a friend once said, he was at all times "one of God Almighty's gentlemen." He was a leader among that brilliant group which included Emerson, Holmes, Hawthorne, Motley, and Longfellow.

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In 1852, Agassiz was awarded the Cuvier Prize by France in recognition of his work on fossil fishes. On a number of occasions he was given tempting offers of chairs in the leading universities of Europe, but nothing could induce him to leave his adopted country. And his fellow-countrymen loved him as a native son. He was America's first great teacher of Nature.

At the age of twenty-two Agassiz wrote to his father, "I wish it may be said of Louis Agassiz that he was the first naturalist of his time, a good citizen, and a good son, beloved by those who know him." No one could have written him a better epitaph. He died in 1873 at Cambridge, Massachusetts. A granite boulder from an Alpine glacier marks his grave and about it grow evergreens brought from the haunts of his boyhood. The impress of his personality upon the thought of his time is as imperishable as are the glacial markings which he was the first to discover.

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CHAPTER XVIII

ROBERT BUNSEN

To invent an instrument capable of detecting so minute a quantity as one two-hundred-thousandth part of a grain of sodium, and to enable the chemist to analyze the stars with as much precision and accuracy as if he could bring them within his laboratory is surely a significant event in the annals of science. That is exactly what Robert Bunsen and Professor Kirchoff of the University of Heidelberg did by their perfection of the spectroscope of 1854. Even the savage could not have failed to observe the rainbow. From the earliest days of glass-making, men must have noted the brilliant patches of color which appear when sunlight passes through angular pieces of glass. But strange as it seems, these phenomena were inexplicable mysteries until Newton demonstrated the composition of white light in 1672. And again nearly two centuries elapsed before Bunsen discovered that he could detect the elements present in a flame by passing its colored light through a glass prism. With this fact as a starting point, working with Kirchoff, he invented the spectroscope, the most marvelous instrument ever devised for analytical work. Even then Bunsen was a chemist of eminence and wide influence.

The spectroscope is an instrument for examining in detail the light emitted by a substance in the incan-

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descent state. It consists essentially of four parts: (1) a very narrow slit through which passes the beam of light, (2) a small telescope called the collimator, at the focus of which the slit is placed, (3) a prism, or a closely ruled glass plate to disperse the light into its component colors, and (4) an observation telescope to produce a magnified image of the spectrum.

Light is an electromagnetic wave movement in the luminiferous ether of space. These waves differ from those that produce heating and wireless effects only in their length. Wireless waves may be several miles in length, while light waves are measured in millionths of an inch. White light is made up of the well known colors of the spectrum, the red waves being longest and the violet shortest. A color scale is like an octave in music. It is simply a matter of pitch. Red is of a lower pitch than violet, and beyond the violet lie the still shorter waves which produce chemical and X-Ray effects, while preceding the red are the vibrations of constantly lower and lower pitch, which give heating and radio effects. When these light waves, which include but a small portion of the total of electromagnetic vibrations, fall obliquely upon one of the faces of a triangular glass prism, their velocity is retarded, the shortest waves being retarded most. Upon emerging from the prism, the colors are found to be separated and a spectrum is produced.

In their early work Bunsen and Kirchoff discovered the following principles of spectrum analysis: (1) *Incandescent solids and liquids and also gases under high pressure give a solid band of color;* (2) *Incan-*

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descent gases under low pressure give a series of bright lines whose number and position depend upon the elements present; (3) *When white light passes through a gas of lower temperature than its source, this gas will absorb from the white light those colors which it would produce, if viewed by itself in the incandescent state.* That is, this band of color from the white light will be crossed by numerous dark lines, their number and position again depending upon the elements present in the cooler absorption gas.

With this instrument and these laws, Bunsen and his co-worker were in a position to make new discoveries and to open a new realm to the scientific investigator. Almost immediately Bunsen discovered two new elements in the water from certain springs. They were rubidium and caesium. But to obtain these rare elements in sufficient quantity for detection, even by this exceedingly sensitive instrument, required the evaporation of forty tons of the spring water. Still, when the residue thus obtained was heated to incandescence in the flame, the characteristic spectra of these hitherto unknown elements were at once revealed. Such a discovery depends upon the fact that each element in the incandescent state gives its own bright line spectrum, the lines being of definite color and position, and unduplicated by those of any other element.

But it was as a means of exploring the heavens that the spectroscope was to find a distinctive place in the world of scientific discovery. As early as 1815, Fraunhofer, an eminent German optician, had observed that

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the sun's spectrum is crossed by a large number of dark lines. He counted as many as seven hundred, but their meaning was a mystery. And no one else was able to explain them. But after the work of Bunsen and Kirchoff, no doubt remained. These dark lines were the absorption spectra due to elements in the state of incandescent vapor in the sun's atmosphere. These vapors, cooler than the solid light-giving portion of the sun behind them, neutralize in the sun's spectrum just the colors which they themselves would emit. Therefore, by devising a spectroscope with a comparison prism, so that the solar spectrum or that of a star may be viewed side by side with the spectra of terrestrial elements obtained in the laboratory, it at once became possible for Bunsen to determine the chemical composition of any heavenly body whose light will reach our telescopes. Thus it has been possible to know that the sun and stars possess practically all of the elements that are found on the earth. Helium, now so useful as a substitute for hydrogen in filling airships, was discovered in the atmosphere of the sun by Sir Norman Lockyer in 1868, long before it was obtained by Sir William Ramsay from certain minerals of the earth's crust. Unmistakably these discoveries point to the common origin of the universe. Marvelous, is it not, this ability to analyze stars so distant that the light which tells the tale left their surfaces hundreds and even thousands of years ago?

But the spectroscope does more than this. It reveals the physical state of nebulae, those vast whirl-

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pools of cosmic action, which may be other worlds in process of formation. Likewise it unveils the secrets of the comets. By replacing the eyepiece of the spectroscope with a photographic plate, these spectra may be photographed and studied at leisure. Great telescopes carry spectroscopic attachments, which disperse the light gathered by the large lens or mirror. The spectroscope, too, discloses the motion of a distant star. When a star is approaching our system, its spectrum is shifted from the normal position it would occupy, if the star were stationary, toward the violet. When a star is moving away from us, the spectrum is shifted toward the red. From the amount of the shifting it is possible to determine the star's velocity with wonderful accuracy. The spectroscope gives us knowledge of sunspots, those immense centers of solar activity so closely associated with electrical disturbances upon the earth. It has made known to us twin stars revolving about a common center of gravity. In 1901, it told the story of a temporary star, which proved to be a vast outpouring of white-hot hydrogen moving at hundreds of miles a second. So far away was this mighty conflagration that the light from it was three hundred years on the way, yet traveling at the velocity of one hundred and eighty-six thousand miles per second.

Bunsen's father was Christian Bunsen, librarian of the famous University of Göttingen. Thus he was born into a literary and scientific atmosphere such as it is the privilege of few to enjoy. After receiving his elementary training in the gymnasium at Holz-

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minden, Bunsen entered the university of his native town in 1828, from which he received his doctor's degree in two years. He spent a winter in study at Paris and some time in travel, after which he established himself as an instructor in his alma mater. Having later served with distinction in a number of the leading universities of his native country, he accepted a professorship at Heidelberg, where he remained for nearly forty years.

Bunsen's first important work was in the field of organic chemistry. For the first time he investigated the chemical character and properties of an organic compound of arsenic, which not only has a terrible odor but is exceedingly poisonous and spontaneously inflammable. In working with the cyanide derivative of this compound, Bunsen suffered from an explosion, which cost him the sight of one eye, and weeks of illness resulted from breathing its fumes. After this experience, Bunsen forsook the field of his first choice and devoted himself exclusively to inorganic chemistry. Here he soon distinguished himself by devising methods of gas analysis which have been standard for more than three-quarters of a century.

During a scientific holiday of several months spent in Iceland, Bunsen carried out one of the most beautiful investigations of natural phenomena known to science. Becoming deeply interested in the geysers, which he saw there, he began to study the causes of their action. Up to this time geologists had regarded the water that spouted from these natural vents in the earth's crust as of volcanic origin. Bunsen's first step

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was to show that this water, like any other spring water, had penerated from the surface. By boiling rocks found in the vicinity with rain water, he obtained an alkaline solution exactly similar to that coming from the geysers. Then by means of self-registering thermometers, which he sunk deep down in the geyser tube, he found that the temperature of the water increased with the depth, becoming at forty-five feet almost equal to the known boiling-point of water at that pressure. As is well known, the boiling-point of water rises with increased pressure and falls as the pressure diminishes. Bunsen concluded that at some point deep down in the geyser tube the water, heated by the hot rocks about it, must suddenly reach its boiling-point, lifting the column above and causing some to overflow from the basin at the surface. This overflow releases the pressure on the whole mass of water beneath, and much of it that is near the boiling-point bursts into volumes of steam, which by its expansive force hurls the water out of the throat of the geyser and high into the air. The "thundering," which immediately precedes the eruption, he attributed to the collapse of steam bubbles, as they rise into the cooler water above.

To confirm his theory, Bunsen made an artificial geyser, consisting of a basin of water having a long tube extending below it. He heated the tube at the bottom and at about the middle point. As the water at the middle reached its boiling-point, all of the phenomena of geyser action were beautifully shown, including the preliminary thundering. That was in

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1846. From that day to this Bunsen's theory of geyser action has been generally accepted by geologists.

But Bunsen was more than an inventor and a scientist. He was a teacher, who numbered among his students some of the most eminent scientists of the century. The famous gas burner known by his name, his calorimeter, his battery, his photometer, and many other pieces of apparatus which were products of his brain will perpetuate his memory among laboratory workers. Resigning his professorship in 1889, Bunsen spent the last decade of his life in quiet enjoyment of the dignity and honor that were due one who had given sixty years of distinguished service to the cause of science.

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CHAPTER XIX

HERMANN VON HELMHOLTZ

Why is it that the sensation of music stirs the depths of the soul? What subtle qualities does sound possess that it can warm the heart or chill the blood? What magic do sound waves bear to produce their wonderful and varied effects? How do the vibrations of the sounding body change? What is the marvelous mechanism of the middle ear? Until the work of Helmholtz these questions and many similar were riddles. But Helmholtz was a master in many fields. Working in the enchanting borderland between physics and physiological processes on the one hand, and aesthetics on the other, he carried out his monumental research on the "Sensations of Tone." He lifted the whole subject of sound out of the shadows of speculation and placed it upon a sure basis of scientific truth.

Helmholtz showed that a pure tone is similar to a pure color. But most tones are not simple. They are compounds — mixtures like those of various spectrum colors. For the first time he brought out clearly the physical causes for the three fundamental characteristics of musical tones — pitch, intensity, and quality. Especially did he point out the immense significance to music of the quality of tones. He

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saw that the vibrating body must produce, and the transmitting medium must carry, every shade of quality, every sensation of sound that the human ear perceives. The quality of the sound must be stamped upon the wave-form. What is it that distinguishes a note played upon a cornet from one of the same pitch and intensity played upon a violin? It is the quality, the variations in the wave-form, the series of partial, or overtones, characteristic of each particular instrument, which are carried by the transmitting medium. Sound, from being a commonplace phenomenon, becomes a physical process of marvelous complexity. Helmholtz proved these facts mathematically and demonstrated them experimentally. He explained the mechanism of the ear and the physiological processes by which these physical waves are translated into human sensations.

Helmholtz, too, gave the physical explanation of harmony in music and the causes of discord. Why are certain chords pleasing and others not? Why does a certain succession of notes produce a melody? What is the cause of beats? What is the physiological significance of these combinations of sound in the sensation of music? Hitherto, men had supposed music to be a gift of the gods, impossible of explanation. But the work of Helmholtz robbed it of its mystery. He was a musician himself of no mean ability and intimately acquainted with the work of the great masters. Discord he traced largely to the prevalence of beats produced by the interference of certain overtones. For the analysis of complex tones he invented

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a unique type of resonator. Each one of the series enables the listener to pick out from a passing medley of sounds the particular tone to which it is tuned. These resonators did for sound what Newton's prism did for light. Just as the prism breaks light up into its simple colors, so do these resonators resolve complex tones into simple ones. But Helmholtz showed that the ear, even without the aid of resonators, may analyze these complex tones and distinguish not only the fundamental but the overtones.

With characteristic thoroughness, Helmholtz mastered the science of human speech. He explained the production of pure vowel sounds and the resonant qualities of the voice. So complete was his mastery of every phase of music and sound that at his death the musical world claimed him as its own.

But the solution of the intricate problems of sound comprised but a small part of what this scientist did. In the field of physiological optics he was equally brilliant. Before he was thirty, he had invented the ophthalmoscope, an instrument by which it is possible to examine the retina of the eye, that wonderful screen which receives the images of human sight and transmits them to the brain. He followed this with the ophthalmometer which permits accurate measurement of the curvatures of the various surfaces of the eye. These two instruments have meant as much to physiological optics as the telescope and graduated circle have to astronomy. Without them the optician would still be groping in the dark. With their aid he is able to diagnose and repair a disordered eye with as much

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certainty as a mechanic adjusts an automobile carburettor. For fifteen years Helmholtz worked in this field and became its foremost authority. He discovered the optical defect known as astigmatism and prescribed the remedy. He became a master of the physical properties of light and the uses of lenses in relation to the eye. Until his work, the action of the eye in accommodating itself to objects at varying distances had been largely a mystery. He demonstrated the muscular action by which the lens of the eye changes its curvature and focal length, as it shifts its view from a distant object to one near by. He studied color and explained why blue and yellow pigments give green, while the pure spectrum colors give white. In a voluminous handbook on optics he recorded the results of all these observations for his own and future generations. It was a splendid contribution to practical science and, had Helmholtz done nothing else, this work would entitle him to lasting recognition.

But at the age of twenty-six Helmholtz had read a paper before the Physical Society of Berlin in which he demonstrated the Law of the Conservation of Energy. It is his greatest contribution to theoretical science and stands on a par with Newton's Law of Gravitation and Einstein's Theory of Relativity. It stamps its author as one of the most profound mathematicians of any age. Although this law is now conceded to be the most far-reaching generalization of the last century, it was received by contemporary scientists as a " fanciful speculation " and even refused

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publication by the leading scientific journal of Germany. Others had done work in this field, particularly Davy, Count Rumford, Mayer, and Joule, but Helmholtz, knowing nothing of their investigations, surpassed them all, and, with a wealth of evidence from every branch of physics, established the law beyond the possibility of doubt. In this task he was ably assisted by Lord Kelvin, the foremost scientist of England, and his life-long friend.

Helmholtz was born at Potsdam, Germany, in 1821, the son of an eminent teacher, a man of rare culture. His mother was a descendant of William Penn. In his veins was German, English, and French blood. He was educated in medicine and surgery, having previously received a broad training in the classics and modern languages. As might be suspected from his later career, he early displayed a strong bent for science. After a few years spent as physician and surgeon in hospital and army work, he became lecturer in anatomy at the Academy of Art and assistant in the Anatomical Museum of Berlin. In 1849, he went to the University of Königsberg as professor of physiology. From 1855 to 1871, he occupied similar positions at Bonn and Heidelberg. In the latter year he became professor of physics at Berlin, a position which he retained until his death in 1894. In 1888, however, he was relieved of teaching and made first president of the Physico-Technical Institute of Berlin.

Possibly Helmholtz' greatest service was that of teacher. His pupils numbered thousands from every country of the globe. His most notable pupil was

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Hertz, who discovered the Hertzian waves and the principles of wireless telegraphy. As scientist, Helmholtz belongs to a class now gone. He was a giant in many fields — mathematics, physics, physiology, music, chemistry, psychology, and even astronomy. With the present high degree of specialization such varied pre-eminence is no longer possible. As a lecturer, he was the first of his own country to popularize science for the common people. Of him London *Punch* wrote:

> "What matter titles? Helmholtz is a name
> That challenges alone the award of fame!
> When Emperors, Kings, Pretenders, shadows all,
> Leave not a dust-trace on our whirling ball,
> Thy work, oh grave-eyed searcher, shall endure,
> Unmarred by faction, from low passion pure."

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CHAPTER XX

ALFRED NOBEL

One day in 1867 Alfred Nobel, a Swedish chemist, was unloading cans of nitroglycerin from his wagon when he discovered a lucky accident. One of the cans had sprung a leak and the liquid explosive had been absorbed by the porous sand in which the treacherous stuff was packed. Furthermore the mixture had hardened into a solid mass. Just at that time Nobel was in serious difficulty over the transportation of his new explosive. A steamship loaded with it and bound from Hamburg to Chili was blown up in mid-ocean. Railroad trains had suffered a similar fate. Three years before, even Nobel's own factory at Heleneborg had been wrecked, with the loss of his youngest brother's life. No one would handle the substance. Governments prohibited its use. But Nobel had devised a simple and safe method of manufacture, and he was not to be daunted by a few explosions. Many times he risked his own life. This conversion of nitroglycerin into a solid by absorption in porous earth saved the day for high explosives. It led Nobel to the invention of dynamite, a comparatively safe explosive, and incidentally made him a wealthy man.

Nobel was born at Stockholm in 1833. His father before him had been an inventor of explosives. When Alfred was in his tenth year, the elder Nobel removed

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with his four sons to St. Petersburg and entered the service of the Russian Government. He soon became known as the foremost chemical expert in the Czar's dominions. For the invention of submarine mines and torpedoes he received twenty-five thousand roubles in gold. In his workshops and laboratories he trained his sons in the use of tools and scientific apparatus. During the Crimean War he was successful in planting mines for the protection of the Russian fleet. When young Nobel was sixteen, his father sent him to America to be trained as a mechanical engineer under the tutorship of John Ericsson, of Civil War fame. But chemistry was the subject of his choice, and he returned to his native land to devote himself to the manufacture of explosives.

Nobel was not the inventor of nitroglycerin. Ascanio Sobrero, an Italian professor at the University of Turin, first made it in 1847. He poured ordinary glycerin drop by drop into a mixture of strong nitric and sulfuric acids kept at a low temperature. Upon pouring the product into water, drops of an oily liquid immediately began to collect in the bottom of the vessel. Sobrero separated this substance, not knowing the explosive nature of the new compound. But he soon discovered this property. One day he was evaporating a minute quantity of it in a glass dish over a spirit lamp, when a terrific explosion occurred and the dish was blown to bits. Had Sobrero followed the usual maxim of the home laboratory worker that "if a little is good, more is better," he would never have known what happened. On another occasion,

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while he was heating a single drop in a glass tube, the stuff exploded, cutting his hands and face with flying glass and injuring others who were standing at a considerable distance away. He tasted the liquid and discovered that even a trace of it on the tongue produced a violent headache accompanied by great weakness of the limbs. He gave a few drops to a dog, and the animal shortly after began to foam at the mouth and vomit. In a few minutes it lay down and almost ceased to breathe. Drugs revived it somewhat, but two hours later, "whining, trembling violently, and beating his head on the wall," the dog died.

Yet nitroglycerin does not readily explode. It will burn quietly with a smoky flame. When poured upon a fire the liquid blazes up but does not explode. Only when it is suddenly heated, or subjected to a particular vibration, such as that produced by the explosion of a fulminate of mercury cartridge, will it go off with that terrific violence which enables it to shatter the strongest materials. When frozen, it is the most sensitive to shock. A laborer was killed by the explosion of frozen nitroglycerin, which he was breaking up with a pick-axe. Yet miners thaw it out in a frying pan over a fire without mishap. Dr. Martin in his book on "Modern Chemistry and its Wonders" tells of a fearful accident caused by the explosion of the frozen stuff. A box of it lay in the baggage room at a railway station. One cold night it froze and, expanding like water, burst its package. In the morning an office boy noticed a yellow liquid oozing from the box and brought a hammer and nails to fasten the top

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and stop the leak. The result was an explosion that shattered the building and killed thirty people.

Up until the time that Nobel began its manufacture on a large scale in 1863, nitroglycerin was only a curiosity. Stop a moment, and consider what a bold undertaking this was. Here was a man who knew full well the dangerous work upon which he was starting. Yet he had the courage of his convictions. He had patented new methods of manufacture and detonation, or means of explosion, and was convinced that mining and tunneling operations would be revolutionized by his inventions. Nothing could deter him. But after the frightful explosion which occurred at his plant in 1864, Nobel was prohibited from building another factory near any town. For a time he was compelled to carry on his investigations on board a barge anchored in Lake Malaren. In 1865 he formed a company and received permission to build a second plant near Stockholm. Still frequent explosions occurred and his new-born industry seemed doomed to failure. No doubt it would have failed had it not been for the fortunate accident which led to his invention of dynamite. As already indicated, dynamite is simply nitroglycerin absorbed in a porous earth, which makes it less sensitive to shock and quite safe to ship.

Within five years from the date of this discovery Nobel had established plants in practically every country of Europe and in the United States. When he came to New York with samples of his "safe explosive," he found that his fame had preceded him.

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The proprietor of the hotel at which he stopped, upon learning what a possibly dangerous guest he might be harboring, asked him to leave. Yet success and financial reward came with a bound. He could not supply his product fast enough and in sufficient quantity. Both nitroglycerin and dynamite were used on a large scale in blasting the St. Gothard tunnel through the Alps. Dynamite was a boon to engineering construction work wherever rock must be removed. In the petroleum fields of the world nitroglycerin found a large use in "shooting" old pumped-out wells, and thereby increasing the flow of oil. A driver with horses and wagon is employed to carry the cans of explosive from well to well. Occasionally, despite the utmost caution, some bump in the road gives to the treacherous liquid the particular sympathetic vibration required for its detonation, and driver and horses together with all the adjacent scenery are blown to fragments. It is never possible to find the slightest trace of the unfortunate man and animals. And even now nitroglycerin plants explode. In 1904, at Hayle, England, through the careless act of a clumsy workman, a terrific explosion occurred, wrecking the plant and producing a volcanic-like roar which was heard for ninety miles.

But Nobel was not satisfied with dynamite. He thought there might be some better solidifier for his liquid nitroglycerin. One day, while in his laboratory, he cut his finger. Immediately he dissolved some guncotton in a mixture of alcohol and ether and placed some of it on the wound. As this was evaporating to

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form what we now call new-skin, a happy thought came to Nobel. Here was gun-cotton, a powerful explosive which had to be dissolved in alcohol and ether in order to form a plastic mass suitable for molding into rods and cutting into grains. Why not dissolve the solid gun-cotton in nitroglycerin and obtain a double explosive? He tried it and the result was *blasting gelatin,* an explosive which is quite insensitive to shock. Mixed with five per cent of petroleum jelly it proved to be an ideal explosive for big guns. Thus Nobel gave to the world the first of those high explosives which have made modern warfare so terrible. This was in 1878. Ten years later he did much work on the perfection of smokeless powder for use in small arms.

Although Nobel placed in the hands of the war makers their most deadly ammunition, it was for the peaceful pursuits of industry that he intended his destructive inventions. In the early days of Rome, to make a cutting three miles long required an army of thirty thousand men and eleven years of time. Nobel knew that it had required one hundred and fifty years to mine five miles of gallery in the Harz mountains. He determined to change all this. Indeed, modern engineering and mining progress would have been impossible without these explosives. To understand this, we have only to consider the Panama Canal, the subways of our big cities, our mountain railways with their numerous cuts and tunnels, the foundations of harbor piers, and the mines for precious metals, ore, and coal.

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But Nobel was more than an inventor of explosives. In England alone, he took out one hundred and twenty-two patents, many of them wholly unrelated to explosives. He was particularly interested in the improvement of firearms, and in his later years he spent much time in an attempt to make artificial india rubber. Nobel passed but a small portion of his life in Sweden. He lived for many years at Paris, and left to build a beautiful villa and a private laboratory at San Remo. With his brothers Robert and Ludwig, he was a pioneer in the development of the Russian oil fields, which proved to be one of his chief sources of wealth. You will be surprised to know that a man who accomplished so much should have been a semi-invalid during the greater part of his life. He was subject to severe nervous headaches always, and had to work with cold compresses about his head. In winter he suffered from bronchitis. An injury to his spine in youth gave him a slight stoop. Still he could never be persuaded to give up his work. In winter, huddled in furs, he drove daily to his laboratory. When his headache became unbearable, he would lie down wherever he might be until the pain eased. A man of less courage could never have won success at so great a cost.

Nobel traveled widely and was a cultured gentleman of art and letters. Besides his native tongue, he spoke Russian, German, French, and English. He was read in the best literature of Europe. Being a lover of pictures, but growing tired of seeing the same ones, he made an arrangement with a Paris art dealer to

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supply him with new scenes at frequent intervals. His favorite poet was Byron. Honors crowded thick upon him from the governments and scientific societies of his own and other lands. He particularly valued the badge of the Legion of Honor of France and his election as a Chevalier of the Order of the Star of the North.

He died in 1896, leaving, as the world knows, his millions for the promotion of peace and scientific progress. The income from his estate is annually divided into five prizes of about forty thousand dollars each, to be awarded to the man or woman who in each case has rendered the most distinguished service in chemistry, physics, medicine, idealistic literature or the cause of world peace. This disposition of his fortune has proved a stimulus to worthy endeavor the world over.

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CHAPTER XXI

SIR WILLIAM PERKIN

In 1856, the year in which Bessemer invented his cheap process for making steel, William H. Perkin, then a lad of eighteen, made the first coal tar dye. Perkin was a pupil of Professor Hofmann in the Royal College of Science at London. Hofmann had suggested to Perkin that he try to obtain the highly valued drug, quinine, from coal tar. Without knowing it, he had assigned to this young chemist what has so far proved an insoluble problem. But sometimes the search for the "impossible" leads to brilliant discoveries. So it proved in this case. One evening, at the close of an unfruitful day's work, Perkin found in his beaker a dirty black mess of aniline oil and other chemicals. His first impulse was to throw it away. Then, as if restrained by the hand of destiny, he paused. Picking up a bottle of alcohol, he filled the beaker and there flashed into a view a beautiful purple dyestuff. It was mauve, the first of the aniline colors.

Standing there in the dusk of his crude laboratory, young Perkin did not realize that he had opened the doors to a vast new field of chemical discovery. Out of this black, foul-smelling coal tar, representing the crystallized essence of ancient geologic forests, was to be distilled the most delicate perfumes known to

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Nature. From it the chemist was to draw the explosive that wounds and the balm that heals. It was to become a treasure house of powerful drugs for the physician and surgeon. Upon this wreckage of former continents was to be built a new industry — yes, a host of new industries.

Perkin's father was a builder and had intended that his son should be an architect. Indeed, he did become one, but it was of a totally different sort from what his father wished. He erected a new edifice in the domain of organic chemistry and, as a result of his discoveries, innumerable factories and even a whole city at Elberfeld, Germany, sprang into being. One day when he was but fourteen Perkin chanced to observe some chemical experiments, which were being carried out by a friend. He was so fascinated that on the spot he resolved to become a chemist. At that same time, too, he became a pupil in the City of London School, where he came under the influence of Mr. Thomas Hall, an enthusiastic teacher of science. Science in those days was not in favor and the chemistry class was assigned for the noon recess. Perkin frequently missed his lunch in order to take in these lectures. He became an assistant to the master, and helped him in setting up his apparatus. At Hall's suggestion, this would-be scientist wrote to the great Faraday of his heart's yearnings, even as Faraday many years before had written to Sir Humphry Davy. In response he received a ticket to the course of lectures which Faraday was then delivering at the Royal Institution. This happy incident probably brought as important bene-

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fits to science as did Faraday's similiar experience a generation before.

By earnest pleading Perkin overcame his father's objections to a scientific career, and was entered as a student of chemistry at the Royal College of Science. This relationship proved a stimulating one. The great chemist was an inspiring lecturer, and so fascinated was Perkin with what he saw and heard at these lectures that he begged permission to listen to them once more in the second semester. In two years he had mastered general chemistry, and had taken the routine work in qualitative analysis. Perkin became so proficient that when he was only seventeen Hofmann appointed him to an assistantship. Unfortunately his new duties left him no time for research, and original investigation was the work upon which he had set his heart. Undaunted, however, he set up a laboratory at home and there he worked evenings and during his vacations. It was in this little home laboratory that Perkin, during the Easter vacation of 1856, made his discovery of mauve.

Perkin was captivated by the beautiful color, the by-product of his research. This was the sort of thing that he had longed to do, and this initial success thrilled him. Turning his attention from the baffling pursuit of quinine, he determined to isolate this color substance, and, if possible, learn its method of preparation. After many days of patient work and many disappointments, he succeeded. It is interesting to know, too, that, had the aniline oil with which he was working been pure, Perkin would not have blundered

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onto the discovery. It was only because of the presence of a small amount of another coal tar product, toluidine, that mauve happened to be formed. But happen it did and fortunately for a wide range of interests the right man was on the spot to observe the event.

Immediately Perkin dispatched some of it to the dyestuff firm of Pullar of Perth for trial. Shortly he received this reply, "If your discovery does not make the goods too expensive, it is decidedly the most valuable that has come out for a long time." Perkin's first step was to patent the process. But the question at once arose as to whether a youth of eighteen could be legally granted a patent. He sought the advice of attorneys and was assured that, since a patent in England is a gift from the crown, there could be no legal difficulty. In due time the patent was granted. Armed with this assurance, Perkin made up his mind to begin the manufacture of the new dyestuff. Against the wishes of his staunch friend, Professor Hofmann, he left his chemical pursuits at the Royal College of Science and began to seek capital for his new enterprise.

Then the tug of war began. As is usual, before every new departure from the accustomed way of doing things, men were openly skeptical. But there were two men who had faith in the genius of young Perkin. They were his father and his older brother. Advancing the savings of a life-time, his father embarked on the new enterprise under the name of "Perkin and Sons." They obtained a site at Greenford Green, near Harrow,

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and began to build their factory in June of 1857. It was soon completed, but there was no machinery to put in it. Such machinery as Perkin required was not then made. At a much later date Perkin said, "At this time neither I nor my friends had seen the inside of a chemical works, and whatever knowledge I had was obtained from books." The difficulties in the path of the new venture seemed even greater than had been the discovery of the dye. Perkin was compelled to design the required apparatus and have it made to order. There was nothing from which to copy. Here was a lad of eighteen inventing plant-equipment which has since become standard the world over. But Perkin had staked his future upon the success or failure of this undertaking and he was not to be turned aside.

At length his factory was equipped but the raw material of chemical manufacture was not at hand. Here was another difficulty. Ever since coal gas manufacture began, the sticky, smelly tar, which fouled the retorts and had to be gotten rid of, had been regarded as pure waste and an unmitigated nuisance. At that time aniline, one of its chief products and the starting point in the preparation of Perkin's precious dyestuff, was almost a curiosity. Far and near Perkin and his brother searched for a supply of benzene from which aniline is made. At length they found it in Glasgow. It cost the extravagant price of a dollar and a quarter a gallon and was of such poor quality that it had to be redistilled.

Now came the supreme test of large-scale produc-

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tion. It is one thing to prepare a substance in the laboratory; it is a vastly bigger thing to manufacture it in commercial quantity. Again Perkin had no guide. His own experiments had pointed the way, and he forged ahead. The first step in the process consisted in "nitrating" the benzene, but where was the nitric acid? It could not be found of sufficient strength for the purpose. Up to this time, although theoretical chemistry had taken great strides, its practical application in the arts and industries was still in the future. Still nitric acid must be had, and, there being no other way, these brothers set about manufacturing it from Chili saltpeter and sulfuric acid. The next step was to reduce this nitrobenzene with hydrogen gas. Once more, special equipment had to be designed. But Perkin triumphed. He began producing aniline in abundance, and soon perfected a process for quickly and cheaply converting it into the coveted dye, called then "Tyrian purple."

One would think that Perkin's troubles should now be over, but in one way they had only begun. Although he was producing his dyestuff in quantity, the public would not use it. He had to educate the dyers. At first his dye would not give a fast color with cotton goods. Perkin's answer was further experimentation. He discovered suitable mordants, chemicals which make a color fast on a fabric. Among them was tannin, now widely employed, but used by Perkin for the first time. He also initiated the practice of dying silk in a soap bath. In less than six months mauve was being successfully used in one of the leading dye-

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houses in England. Its introduction then became rapid and certain. The use of the new dye spread throughout England and on the continent. New concerns for its manufacture sprang up both at home and in France. The plant of Perkin and Sons was taxed to its utmost capacity, and financial success smiled upon them. But this was only the beginning.

Perkin and many others now turned their attention to the preparation of new dyes. His triumph had stimulated chemical discovery and the application of chemistry to industry as nothing else had ever done. What had before been chemical curiosities were rapidly becoming everyday necessities. Perkin soon became recognized as the leading European authority on dyes. In 1861, when only twenty-three, he was invited to lecture before the Chemical Society of London on coal tar colors. Imagine the feelings with which he noted among his hearers the distinguished Michael Faraday and the pleasure with which he received the congratulations of this great master upon his lectures. In 1866 he was elected to a Fellowship in the Royal Society, and at about this time began to contribute papers to the Transactions of the Chemical Society.

In 1868 Graebe and Liebermann had discovered that alizarin, the famous "Turkey Red," is a derivative of anthracene, another of the crude products of coal tar. But their laboratory method of preparation was too expensive. Immediately Perkin set to work to discover a commercial process, just as he had done for mauve. In less than a year he had succeeded and in June of 1869 took out a patent. But his German

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rivals had independently discovered the same process and had beaten him to the patent office by one day. Perkin, however, was the first to enter the manufacturing field. Again he had to devise his own machinery and beg the distillers of coal tar to supply him with anthracene. But at the end of the year he had produced one ton of the new dyestuff. This event sounded the death knell of the madder root industry, from which alizarin had been made, and sent the price of anthracene from practically nothing to five hundred dollars a ton. The orders for the new color nearly swamped Perkin's plant at Greenwood Green.

In 1874, less than twenty years after his first discovery, Perkin sold his dye plant and retired to a life of chemical research. Here was a man who, almost single-handed, had opened a new field of applied chemistry and then, with untold wealth within his grasp, relinquished all to devote his life to the cause of science. He had accomplished his purpose. The modest fortune which he had acquired was sufficient for his needs, and with this security he returned to the field of his first choice. No more delightful life than Perkin chose can be imagined. Working in the quiet of his own private laboratory, he was free to pursue whatever investigation pleased his fancy. He became a pioneer discoverer in organic chemistry, and few have enriched the subject with a greater amount of original work.

In 1879 Perkin was awarded the Royal Medal of the Royal Society and ten years later the Davy Medal. In 1906 he was knighted. In that same year, the

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semi-centennial of his discovery of mauve, he was honored by the chemical societies of both continents. At New York he was presented with the first impress of the Perkin Medal, founded in his honor, and since awarded each year to that American chemist who has rendered the greatest service in the field of applied chemistry. In the following year he died, universally recognized as one of the great chemists of the last century.

It seldom has been given to any man to witness such an ever-expanding triumph of discovery as it was to Perkin. Gorgeous dyes of every shade and hue appeared in bewildering profusion. Dye works sprang up everywhere, and, to supply the chemicals needed for the new work, many other plants were called into being. But owing to the indifference of the British Government and its universities, the new industry passed largely under German control. The tragic importance of this blunder became only too apparent in the World War, when it was discovered that the myriad products of coal tar were indispensable to victory. Indeed it was because of this lack of encouragement that Perkin retired so early.

In Germany the manufacture of dyes and dozens of other coal tar products became a leading industry of the nation. In one city it was the sole occupation. In its extensive chemical plants were employed eight thousand workers and three hundred and thirty trained chemists. One of the triumphs of the German chemists was the preparation of synthetic indigo. Indigo is older than the Pharaohs, and from time immemorial

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it had been made from the indigo plant. But in 1879 the German chemist Adolph von Baeyer, obtained indigo artificially from coal tar. Yet it was only a laboratory curiosity, until, after fifteen years of research work by an army of trained chemists and the expenditure of millions of dollars, the *Badische Annilin und Soda Fabrik* placed it upon the market at a few cents a pound. Immediately the value of the annual crop of the indigo planters dropped from twenty millions to less than half a million.

In the field of artificial perfumes Perkin was the pioneer. With his synthesis of coumarin, the scent of new-mown hay, he led the way. The story of the other coal tar products is a romance in itself. From no other scientific discovery has there flowed such a flood of products and such a wealth of new knowledge as has proceeded from the synthesis of mauve. Even the alchemist in possession of the Philosopher's Stone could never have dreamed of such transformations. And the end is not yet.

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CHAPTER XXII

MADAME CURIE AND RADIOACTIVITY

To obtain the gram of radium — a small thimbleful — given by the women of America to Madame Curie in the spring of 1921 required six hundred tons of ore and the labor of five hundred men for six months. The process of extraction consumed ten thousand tons of distilled water, one thousand tons of coal, and five hundred tons of chemicals. The distilled water would fill a cylindrical tank twenty feet in diameter and one thousand eighteen feet tall — taller than the Eiffel Tower in Paris, and nearly twice as tall as the Washington Monument. The ore and coal would make a train of forty cars and the chemicals would require for their storage a warehouse thirty feet long, twenty-five feet wide, and twenty feet high. If these figures seem large, consider that to obtain the scant five ounces, which represent the world's total supply of this precious substance, they must be multiplied one hundred and forty times. This would mean the labor of thirty-five thousand men for a year, and a train-load of raw materials four hundred and twenty-seven miles long, and all for a product so small that it could be carried by a toddling infant.

In the early nineties of the last century there came to Paris a poor, untutored Polish girl named Marie

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Sklodowska. She had come to the French capital friendless and without funds, to obtain an education and in particular to devote herself to the study of science. As a little girl, she had grown up in the laboratory of her father, Dr. Sklodowski, who was a professor in the gymnasium at Warsaw. There she acquired the interest in scientific investigations which was to shape her whole life. When her association with the leaders of the revolutionary party in her native land made her stay in Warsaw unsafe, she fled to Paris, where she has since lived and worked. For many months her diet consisted of bread and milk, and she supported herself by private tutoring, and washing bottles at the Sorbonne. Her main efforts were directed toward securing a degree in mathematics and the physical sciences from the University of Paris. The superior knowledge of this Polish girl, so eager to learn, soon attracted the notice of Dr. Lippmann, the head of the department in which she worked. Through him Miss Sklodowska formed an acquaintance with Pierre Curie, also a student of science at the Sorbonne. Stimulated by a common interest in the same field of work, this friendship deepened with the months, and in 1895 they were married. Madame Curie assisted her husband in his work and at the same time carried on her own studies. Three years later she received her degree and turned her attention to original research. She had completed her preparation at one of the most tremendous moments in the history of scientific investigation, and fate had placed her in the most auspicious spot for the rôle which she was to assume.

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Of course all the world knows that Madame Curie discovered radium, but, before she asked and received permission to make her systematic search for radio-active substances, three notable events had occurred. In 1879 Sir William Crookes discovered that the negative pole of a vacuum tube, when excited by a high-tension source of electricity, gives off a peculiar set of rays, which he named "cathode rays." Later it was shown by Sir J. J. Thomson and others that these rays consist of particles of negative electricity, to which has been given the name of electrons. Thomson also showed that these electrons, now so familiar to the general public and in particular to radio enthusiasts, weigh about two-thousandths as much each as the atom of hydrogen, the lightest of the elements.

Many workers felt that they were upon the verge of important discoveries. Still, years passed and the cathode rays promised to be little more than a scientific curiosity. Then in December, 1895, the world was startled by news from Germany that Professor William Conrad Röntgen had obtained from a vacuum tube a wonderful new light, which made visible to human eyes the interior of an opaque object. Coins in a purse, nails in a shoe, the bones of the hand stood revealed as shadowy, ghost-like silhouettes. Certain minerals such as zinc blende and willemite were caused to fluoresce brilliantly when placed in the path of these rays. Röntgen showed that heavy, black, light-proof paper was no barrier to their penetrating power, and more important still, that they would affect a photographic plate. The amusement and incredulity

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with which these reports were at first received quickly turned to astonishment and admiration when the abundant proof of the discovery became known. Within a month the X-Rays, as this new radiation had been named by Röntgen, became the talk of all Christendom, and radio-photography was the chief object of interest in every capital of the world. This and other discoveries soon to follow caused the last century to pass out in a blaze of scientific excitement unequaled since the time of Davy.

But what are these X-Rays, discovered, as they were, by mere chance? How do they arise and what is their nature? Röntgen learned that wherever the cathode rays strike upon an object, as the opposite walls of the tube or a screen placed in their path, an invisible radiation is produced, which has the power to penetrate opaque matter, affect a photographic plate, render a gas a conductor of electricity, and cause fluorescence in certain minerals. It is now known that these rays are short waves in the ether, waves so short that it would take two hundred and fifty million of them to make an inch. The rate of vibration necessary to produce them is *three quintillion* per second.

The third discovery preliminary to the work of Madame Curie centers about Henri Becquerel, an associate of hers at the University of Paris. The discovery of X-Rays stimulated Becquerel to investigate the light-giving properties of phosphorescent substances. Is it not possible, he asked, that the radiations of these substances may also penetrate opaque matter? Becquerel selected for his experiment

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the metal, uranium. He exposed it to the sunlight and then placed it upon a photographic plate wrapped in black paper. Upon developing the plate, he found that it had darkened. He repeated the experiment using thin metal plates instead of black paper and obtained a like result. Here was, indeed, a radiation similar to X-Rays. But one day the sun did not shine, and Becquerel, wrapping the plate in black paper, placed the uranium upon it and thrust them into a drawer, where they remained for several weeks. Then out of curiosity he developed the plate to discover whether there had been action when the metal had not first been exposed to sunlight. There had. The answer was clear. Uranium of itself did give off rays capable of penetrating opaque matter. Without then knowing it, Bacquerel had found the key to the anteroom of subatomic mysteries.

At this point Madame Curie, whose interest had been fired by the new discoveries, began a systematic search to discover whether any of the other elements might also possess radioactive powers. Aside from uranium, she found only one, thorium, which did. In making this search she availed herself of Becquerel's discovery that these rays are able to ionize a gas and render it a conductor, thus discharging a gold-leaf electroscope whenever a radioactive substance is brought near it. But her next step marked a turning-point in this fascinating field of study. When she examined pitchblende, the parent mineral from which uranium is obtained, she discovered a degree of activity four times as great as that produced by all of the pure

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uranium that could be extracted from this sample. This could have but one meaning. There must be in pitchblende some other substance more radioactive than uranium itself.

Assisted by her husband, Madame Curie began the search for this new element. The Austrian Government presented them with one ton of pitchblende from its rich mines of uranium at Joachimsthal, Bohemia. The undertaking was a prodigious one. Many of the elements, both common and rare, are found in pitchblende. To separate them and examine each part for radioactive material was a Herculean task. There was always the possibility, too, that some of the precious stuff might escape. Yet with the electroscope it is possible to trace this material wherever it may go. So delicate is this test that so minute a quantity as one fifty-billionth of a gram may be detected with ease, and Professor Soddy states that probably one-tenth of that amount would not escape discovery. This British investigator also states that were one-half of a grain of radium salt to be distributed "equally among every human being at present alive in the world, and one such portion were returned to us, it would prove sufficient for detection and identification by means of a gold-leaf electroscope with the greatest ease."

Beginning their investigations in a large building, the quantities containing radioactive material gradually became smaller and smaller until the test tubes of their laboratory were able to hold them. Their first discovery was that of a powerful radioactive sub-

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stance, which proved to be a new element and was named by Madame Curie *polonium* in honor of her native country. But further investigation showed that, associated with the barium fraction of the separation, was a still more active element. Patiently they pushed forward their search. Gradually, by numerous processes of solution, crystallization and recrystallization they brought this element into constantly closer quarters. Finally in 1898 they separated it and named it *radium*. It proved to be two and a half million times as active as uranium. It would affect photographic plates, ionize the air, excite phosphorescence, liberate heat, effect chemical changes, and destroy minute organisms. That it was a new element Madame Curie proved by the distinctiveness of its bright-line spectrum from that of any other element. In a short time she had determined its atomic weight and found it to be 226. This placed it in the same group in the periodic table as barium, strontium, and calcium. In 1910 she obtained it in the free state. It proved to be a pure white metal similar to calcium, melting at seven hundred degrees Centigrade and quickly tarnishing upon exposure to the air.

Thus the Curies triumphed. True, from this enormous quantity of raw material they had obtained but a few milligrams of radium. But it was the most remarkable element that men had ever seen. In the light of its astonishing properties mysteries which only a generation before had been regarded as insoluble were to disclose their secrets. In the deep insight which it has given into the structure of the atom, this

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discovery is without a parallel. If it in the end gives us the key to the vast reservoirs of energy locked up within the atoms of the elements, Madame Curie's discovery of radium will be up to this point of evolution the supreme achievement of the race.

Madame Curie continued her work on radium. In 1903 as a result of these investigations she was awarded the doctor's degree by the University of Paris. In that same year the Curies received the Davy Medal of the Royal Society of London. The Nobel prize for the most notable achievement in chemistry was divided in 1900 between them and Becquerel. Again, in 1911, the Nobel prize was bestowed exclusively upon Madame Curie because of her subsequent work in the field of radioactivity. This is the only instance in which the same individual has been twice thus honored. Upon the accidental death of her husband in 1906, Madame Curie succeeded to the professorship which he had held at the Sorbonne. There, in 1907, she delivered a lecture on polonium, which was attended by the foremost scientists of Europe and the leaders of wealth and fashion in the gay French capital. At the outbreak of the World War the University of Paris established a radium institute for research in radioactivity, and Madame Curie was placed at its head. Later on she established a similar institute in her native city of Warsaw.

Interesting as the discovery of radium is, the immense significance of this element lies in its activity. Radioactivity is the one process in Nature which we can neither hasten nor retard. Ceaselessly, without

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apparent diminution, at a definite and unalterable rate it gives forth its supply of energy. Madame Curie showed that a gram of radium will give off sufficient heat every three-quarters of an hour to raise the temperature of an equal weight of water from the freezing point to the boiling point. In the complete disintegration of a gram of radium it is estimated that two billion nine hundred million calories of heat will be evolved. Since the complete combustion of a gram of coal gives eight thousand calories, of which only twenty-two hundred actually come from the coal, it will be seen that the energy supplied by radium is more than a million times greater than that furnished by the chief fuel of the present age.

No sooner had the announcement of the discovery of radium been made than physicists began an investigation of its properties. Chief among these scientists were Sir Ernest Rutherford, Sir William Ramsay, and Professor Frederick Soddy. To Rutherford we owe the first analysis of the complex radiations emitted by all radioactive elements. He showed that there are three distinct sets of rays, which he called *alpha rays*, *beta rays*, and *gamma rays*. The alpha rays are shown to be positively charged particles shot off with a velocity of about twenty thousand miles per second. They have small penetrating power, but great efficiency in rendering gases conductors. One of the most remarkable facts about them is that they have been found to be *positively charged atoms of helium*. Thus under our very eyes are we able to witness the transmutation of an element. The beta rays consist of

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streams of electrons projected with velocities ranging from sixty thousand to one hundred eighty thousand miles per second. They have been found to be identical with the cathode rays of the vacuum tube. Thus they are easily attracted by the positive pole of an electromagnet, while the alpha particles are deflected in the opposite direction, although to a much smaller extent. They also have great penetrating power. The gamma rays are waves in the ether similar to X-Rays, only shorter. Their penetrating power is about one hundred times greater than that of the beta rays, and they are wholly uninfluenced by a magnetic field. It is thought that they are produced by the impact of beta particles on matter through which these electrons pass, just as X-Rays are produced by the cathode rays.

But what is the source of this seemingly inexhaustible supply of radioactive energy? At first this was a puzzle, but experiments have shed light upon the mystery. Sir Ernest Rutherford showed that if a sample of radium salt is dissolved in water and the solution evaporated to dryness, the salt will lose the greater part of its activity. A remarkable result follows. Upon standing, the radium gradually recovers its power until at the end of thirty days it is as active as ever. Rutherford also discovered that in the solution and evaporation of the radium salt an intensely active gas is given off. This gas he collected and named *radium emanation.* It causes fluorescence in the dark and possesses all the properties of radium. He found it to be a true gas and a new element, which has been called *niton,* and takes its place in the periodic

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table with the rare gases of the atmosphere. Its atomic weight is 222, just four less than that of radium. It has also been shown that helium, whose atomic weight is 4, is formed at the same time. Therefore, physicists have concluded that the radium atom disintegrates, yielding the alpha particles, which are helium atoms, and a new element, niton. These eruptions of myriads of radium atoms also liberate a ceaseless supply of energy. Thus this source of energy is subatomic. We are mere onlookers of the process. We see the birth of two elements by the transmutation of another, but it is entirely beyond our control.

Yet the most extraordinary part of this phenomenon has not been told. The life of this new element, niton, is short. The activity of the emanation, or niton, rapidly decays from day to day until at the end of thirty days it is practically zero, and the element has successively passed through a series of disintegration stages, giving rise at each stage to a new product. Just as the emanation loses its activity, the parent radium regains its lost power, there being at any moment a perfect balance between the two. The sum of the two activities is always the same. A fresh supply of emanation is always being manufactured by the radium at a definite rate, due to the disintegration of its atoms. In 1903 Sir William Ramsay and Professor Soddy demonstrated that the radium emanation in its process of change produces helium, and that this decay gives a series of new elements each differing in its atomic weight from the preceding one by four. The end product seems to be lead, and each successive

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change is accomplished by the expulsion of an alpha particle, or, what is the same thing, a helium atom.

From the known rate at which radium decays it has been possible to calculate its period of average life. This is best stated as follows: In seventeen hundred and thirty years half of any given quantity of radium will have disintegrated. In another period of seventeen hundred and thirty years half of the remainder will disintegrate, and so on. From this calculation it was seen that in past geologic time there must have been prodigious quantities of radium in the earth, in order that there should be any left now. But the geology of the rocks and the fossil records of animal and plant life disproved any such conclusion. Physicists were compelled to believe, then, that radium is being produced from some other element as fast as it disappears. Such indeed seems to be the case. It has been definitely proven that radium is a disintegration product of uranium, just as niton is a product of the decay of radium. The whole series has been established from uranium to radio lead. There are no less than fourteen disintegration products, each differing from the preceding by a single helium atom. Two other elements, thorium and actinium, also give disintegration series.

The average life period of uranium has been computed as eight billion years. It will thus be seen that the geological past of the earth is much longer than had been previously supposed. The biologist, who was scraping along on a niggardly hundred million years,

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may now have almost infinite periods of time for his processes of evolution.

Upon the problem of solar and celestial energy the new knowledge of radioactivity throws a flood of light. What is the source of these ceaseless fires? With no other known origin than that of combustion, it had seemed certain that they must cool in the not distant future. They could not be eternal. The prodigal waste of these supplies of cosmic energy is appalling, and yet there is no apparent diminution. As far as man is able to determine they are infinite. But in 1868, Sir Norman Lockyer, by means of the spectroscope, discovered helium in large quantities in the atmosphere of the sun. Indeed, it was not until 1895 that Sir William Ramsay found this element in certain minerals and a little later identified it as one of the rare gases of the earth's atmosphere. But there was a significant fact connected with these discoveries. Helium always occurred in the radioactive minerals of uranium and thorium, and in no others. In the light of our new knowledge of radium is it not probable that the large quantity of helium in the sun's atmosphere is due, as it undoubtedly is on the earth, to the disintegration of radioactive elements? Is this not the explanation of the solar fires? May it not be true that just as radium here is disintegrating and being at the same time reproduced in equal and unalterable quantity, so it is on the sun? Is it too fantastical to assume that in the radioactive cycle we are observing the one majestic example of perpetual motion to be found in all the universe?

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As Professor Soddy has suggested, may we not be standing at a turning point in the evolution of the race? Just as the cave man, milleniums ago, gained a mastery of fire, so may the scientist tomorrow learn to liberate and control these vast reservoirs of sub-atomic energy. Certain it is that present investigations are moving in that direction. When that day arrives, the material power which will pass into human hands will place the race upon a plane of development that will dwarf the mightiest achievements of the present age. The energy locked up within the atoms of a pound of uranium oxide would be equivalent to that liberated in the combustion of one hundred and sixty tons of coal. The store of energy in a ton of uranium would light the city of London for a year. Professor Le Bon has showed that the smallest French coin contains energy equal to eighty million horse-power. Every atom is a fount of energy.

The knowledge of radioactivity has given us a new meaning of the atom. There is no longer a shadow of doubt as to the existence of atoms. But they are not hard, indivisible particles of matter. We now know atoms to be systems of planetary electrons, moving at inconceivable velocities with reference to central nuclei of positive electrification. There are between these electrons and their central sun dreary wastes of space, relatively as vast as the distances between the members of our solar system. It is the disruption of these atomic systems of radioactive elements, with the evolution of electrons and alpha particles, that liberates the energy which we some day hope to control. Sir

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Oliver Lodge estimates that one-seventieth of a grain of radium hurls into space thirty million of these electrons per second with a velocity approaching that of light. The problem of the future is to discover means of initiating and controlling at will the liberation of this pent-up energy, whether it be from radioactive elements or those of lower rank.

But aside from its theoretical interest radium promises to be of priceless value in the saving of life. Its value is not measured in dollars and cents, but in terms of human energy, health, and happiness. For radium promises, if not absolutely to cure the most malignant cases of cancer, at least to place them under control and to banish forever this scourge in its milder forms. At the Memorial Hospital in New York, one of the most notable centers for the treatment of cancer in this country, the emanation is pumped each morning at nine o'clock from four grams of radium, securely housed in a steel safe, surrounded by thick concrete walls. The glowing gas, the active essence of radium, sealed in tiny capsules and placed in the diseased tissues soothes and heals.

So the knowledge of radioactivity has opened the way to an understanding of the underlying mysteries of energy and matter. To Madame Curie, and those who have labored before her and with her, the world will not soon forget its debt.

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CHAPTER XXIII

GEORGE WESTINGHOUSE

One bright morning in the spring of 1869, a train consisting of locomotive, tender, and four passenger cars pulled out of the Pittsburgh station of the Panhandle Railroad. Nothing unusual marked the appearance of this train. Gradually the young engineer, Dan Tate, increased the speed to thirty miles an hour. Then barely two blocks ahead, he saw a drayman blunder upon the tracks. Frantically the unfortunate man whipped up his horses, but was thrown sprawling across one of the rails. Something had to be done, and that speedily. Reaching for the brake valve, Tate gave it a mighty turn. With a jolt and grating that sent the passengers sliding from their seats with bruised shins and battered hats, the train came to rest just four feet in front of the drayman. For the first time in the history of railroading, compressed air had been used to stop a train. Rushing from the main reservoir into the line and cylinders, it had driven out the brake pistons with irresistible force. The vexation of the disgruntled railroad officials and their invited guests quickly turned to admiration, as they learned the cause of their shaking up. This unexpected and dramatic incident banished the proverbial skepticism with which the new invention had been greeted, and marked a new day in railroading.

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When the train returned to Pittsburgh from its trial trip, a young man, not yet twenty-three, entered the telegraph office and sent this message to his father in Schenectady, New York:

"My air brake had practical trial today on passenger train on Panhandle Railroad and proved a great success. GEORGE."

The young man was George Westinghouse. One day about two years before, while traveling from Schenectady to Troy, his train had unexpectedly come to a standstill. Going forward to learn the cause of the delay, he discovered two battered freight locomotives and heard the story of a head-on collision. "But why," asked Westinghouse, "should this collision have occurred?" The track was perfectly straight for a considerable distance and the roadbed smooth. Upon inquiry the boss of the wrecking crew answered,

"No, the engineers saw each other, and both tried their best to stop, but they couldn't."

"Why not? Wouldn't the brakes work?"

"Oh, yes, but there wasn't time. You can't stop a train in a moment."

That was the incident which set Westinghouse to thinking about the air brake.

Westinghouse was born in October of 1846 at Central Bridge, Schoharie County, New York, the descendant of early Dutch settlers. His father was an inventor of some note and the proprietor of a carpenter and machine shop, which he later moved to Schenectady, where George spent most of his boyhood.

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Westinghouse was a typical boy. He liked to play, and he disliked school. He possessed a strong bent for working with tools. He was always contriving something, much to the disgust of his father, who regarded his projects as mere "trumpery." But while still a lad, he built with his own hands a small rotary steam engine, with which he ran a boat on the Erie Canal.

One Saturday morning, the elder Westinghouse led George to a pile of pipe and gave him instructions to cut it into pieces of a certain length, stating that he was to be gone for nearly a week and this would provide a job during his absence. This dealt a crushing blow to George's plans for play. But, as his father talked, he had been thinking out a plan of action. He rigged up a combination of tools, which, when attached to an engine, automatically fed the pipe and cut it into the required lengths. In this boyhood incident we see foreshadowed that fertility of resource which was to make him one of the eminent inventors of his time.

Although only fifteen when the Civil War broke out, Westinghouse tried to run away from home to enlist, and was prevented from doing so only by the timely appearance of his father. Two years later he did enlist, and rose to the post of Acting Third Assistant Engineer in the Navy. When mustered out of the service, he entered Union College, in his home town. But he had no bent for school. Languages and the intricacies of mathematics bored him. His heart's desire was to work at a bench and a lathe, to fashion into concrete form the creations of his brain. In

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after years he had occasion to regret the lack of a college education, which this short-sighted view denied him.

Westinghouse's first invention was a mechanical car-replacer. One day, while still less than twenty, as he was returning from Albany the two rear cars of the train just ahead jumped the track. For two hours he watched the train crew, as they slowly and laboriously pried the cars back onto the rails. "That was a poorly handled job," he remarked to a friend. "It was tedious, but that couldn't be helped," was the reply. But it seemed to Westinghouse that it could be helped. While the men worked, he had designed a car-replacer. It was to consist of a set of rails which might be clamped to the track and run off at an angle like the frog of a switch. By hitching the engine to the cars the painful process just witnessed could be wholly eliminated and the time reduced to a few minutes.

Before he slept that night he had made drawings of his device and the next morning he constructed a model. But he could not interest his father. Financial aid, he found, must come from another source. He approached a number of business men of the town, and fortunately two of them had sufficient faith in Westinghouse to risk five thousand dollars apiece on the enterprise. He obtained a patent and began to manufacture and sell his invention. Soon he had the satisfaction of seeing it in use on many railroads and himself a prosperous business man.

At this point in his career the incident occurred

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which caused Westinghouse to see the need for a rapid action train brake for use in times of emergency. The idea fascinated him. How could it be accomplished? He first conceived of a brake chain extending the whole length of the train, which could be drawn taut by some device under the control of the engineer. But a little reflection convinced him that this clumsy device would never work. Still such a brake must be invented, and Westinghouse never doubted that he was the man to invent it.

His next idea was to operate brakes by a cylinder and piston placed under each car and driven by steam from the engine. But the difficulties of condensed steam in the pipes and cylinders, especially in cold weather, caused him to abandon this scheme. Then a seemingly trivial incident solved the problem of the brake and changed Westinghouse's whole future career.

One noon hour, sitting in his father's shop, Westinghouse was approached by a young woman, who asked him to subscribe to a magazine. To her timid solicitation, he answered somewhat brusquely, as he waved her away, "No, I never read magazines."

But, noting the disappointment on her face, Westinghouse relented. Pulling a two-dollar bill from his pocket, he entered his name for a three months' subscription. In glancing through the specimen copy, his eye had been caught by an article on the Mont Cenis Tunnel, which was then being bored in Switzerland. Without knowing what an important part that article was to play in the solution of the problem

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which constantly haunted him, he specified that his subscription must begin with this number.

After its arrival the magazine lay for several days unopened upon his desk. Then one evening he picked it up, and turning to the article which had aroused his interest, learned that compressed air was solving the problem of the Mont Cenis Tunnel. A compressor supplied air at six atmospheres pressure to a rock drill located three thousand feet away.

Westinghouse threw down the magazine in triumph. Here was the answer to his puzzle. Air — yes, that was the power needed to operate his brake. Unlike steam, it would not condense. It would not freeze. Its power could be transmitted with perfect ease throughout the longest train. Quickly he designed his brake system and made application for a patent.

Once more Westinghouse approached his father in the hope of obtaining financial assistance. But the deep-rooted Dutch conservatism of the elder man held him back. Again Westinghouse was compelled to seek capital among strangers. In the meantime, he had married an estimable young woman, of Roxbury, New York, whom he had chanced to meet on a train during one of his frequent business trips. In the hope of getting the parts for his car-replacer made more cheaply in Pittsburgh, they now moved to the steel metropolis, in the industrial growth of which Westinghouse was to be so large a factor.

Westinghouse soon had a working model of his brake system ready for operation. The one idea that dominated his every waking hour was how to get it

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introduced to the railroad public. Given an opportunity to demonstrate its superiority, he had not the slightest doubt of the outcome. In his travels as the salesman for his car-replacer, he constantly met railroad officials, and everywhere he talked about his air brake. But Westinghouse's experience was like that of many another inventor. The scheme was branded as "visionary," "impractical," "it would never work." Still Westinghouse never faltered. He had already succeeded in interesting a young man of Pittsburgh named Baggaley, who had some means and with whose assistance he had built his working model. Together they began to besiege the officials of every important railroad for the opportunity to make a public demonstration. They wanted the railroad to provide the train and bear the expense. But everyone balked. The train might be wrecked with loss of life and a waste of the stockholders' money. Everywhere they met with rebuffs. At length W. W. Card of the Panhandle Railroad became convinced of the superiority of Westinghouse's brake. He induced his company to supply a train, upon condition that Westinghouse would equip it at his own expense and reimburse the company for any damage to the locomotive or cars. Tired of delay, Westinghouse agreed to the terms.

The day of trial arrived and passed, as already described. A steam-driven pump mounted on the locomotive supplied air at a pressure of sixty or seventy pounds per square inch to a main reservoir. A valve mechanism near the engineer's seat controlled the service pipe, which passed beneath the train to

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the brake cylinders, one for the tender and one for each car. The ordinary hand-brake gear was connected to the piston of each cylinder. Flexible hose connections were provided between the cars. To set the brakes, the engineer turned the valve admitting air to the pipe line and brake cylinders. The air pressure thrust out the pistons and set the brakes. To release the brakes, the engineer turned the valve cutting off connection with the main reservoir and at the same time opening the service pipe and cylinders to the outside atmosphere.

Westinghouse's decisive triumph on the initial trial of his new brake headed him for success. He abandoned his car-replacer business and with the help of his friend Baggaley rented an old foundry in Pittsburgh for the manufacture of his brake. Official conservatism disappeared. The Pennsylvania Railroad now offered a train and requested a demonstration. This was as successful as the other, and he was permitted to use this same train for demonstrations in Philadelphia, Chicago, and St. Louis.

Westinghouse's patent was issued in April, 1869. In July he organized his first company, with himself as president and some of the most prominent railroad men of the country as directors. Soon all the more important railroads had installed his brake. From that day to his death Westinghouse never lacked funds to carry out his numerous projects. In the following year, he went to England, where after a hard-fought battle he overcame British reserve, and was largely

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successful in introducing his brake there and on the Continent.

Yet vast as was the improvement of the air brake over the clumsy system that it displaced, it was still a crude device. Westinghouse immediately set out to improve it. His first mechanism made no provision for setting the brakes, if a train should break in two. To overcome this defect, he brought out the automatic brake. Decrease of pressure from a ruptured hose connection or any other cause, whether it be accidental or not, would stop the train. The device which accomplished this is known as the "triple valve." Under Westinghouse's later development, it came to represent one of the highest examples of applied invention.

Another and most serious difficulty was that the air would not set the brakes on the rear cars as quickly as it did those on the forward part of the train. In short passenger trains this was of slight importance, but, when a long freight train was brought suddenly to rest, the interiors of the end cars resembled a wreck. It was freely predicted that air would never solve the problem. These criticisms challenged Westinghouse's pride of invention, and he determined to silence the skeptics. He overcame every obstacle, and in a series of demonstrations given in three successive years at Burlington, Iowa, he convinced the railroad world of the superiority of his all-air-system. By 1888 his air brakes were handling the longest freight trains with ease and safety. Quickly and surely he brought them to rest, yet gently as a spent golf ball rolling across the green.

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Westinghouse was the first in America to apply compressed air to the complex system of "interlocking" train signals so essential to the safety of modern travel and to the elimination of congested traffic. The system which he devised is now in universal use. What the railroading of the world owes to the Westinghouse air brake and signalling inventions no man can measure. Certain it is that without them the complex industrial organization of modern industry, dependent as it is upon the capacity and efficiency of our arteries of transportation, would still be in the future.

Yet Westinghouse was active in many fields. His applications of compressed air exhausted but a small portion of his energy for invention. It is no exaggeration to say that the manufacture and distribution of electric power, vast as this industry is, owes more to Westinghouse than to any other man. The introduction of the alternating current, which now supplies ninety-five per cent of the world's electrical needs, was accomplished by Westinghouse against the most formidable opposition. In his shops and under his leadership were developed the first large alternating current generators, the transformer, the rotary converter, the induction motor, and the turbo-electric generator. These are the fundamentals of modern electric development. When even so great a scientist as Lord Kelvin pronounced judgment against the alternating current, and the ill-considered opposition of Edison was marring an otherwise brilliant career, Westinghouse had the insight and intuition to understand the

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inadequacy of the direct-current system to meet the electrical needs of the coming age.

In opposition to the Edison Electric Company, Westinghouse obtained the contract for the illumination of the World's Fair at Chicago in 1893, at a saving of one million dollars to the promoters of that undertaking. Restrained by the Edison Company from using their electric lamp, Westinghouse devised the so-called "Stopper Lamp," which satisfied perfectly the emergency need. Within a few months he devised machinery, including a glass works, for producing two hundred and fifty thousand of these lamps, besides supplying a constant stream of replacements. To supply the electric power he built the largest central station then in existence, and installed twelve huge generators, each of one thousand horsepower. As these were of the alternating current type, this colossal experiment dealt a death blow to the opposition to this new form of electric energy. It afforded also the largest and most brilliant exhibition of electric lighting that the world had ever seen.

The Chicago Exposition paved the way for a still greater triumph at Niagara Falls. For a number of years there had been under consideration a plan for utilizing a portion of the energy of the great cataract for the development of electric power. Whether direct or alternating current should be the form of power generated was the last question left for decision. With the laurels of the World's Fair fresh upon him, Westinghouse entered the lists for the alternating current, and won. He also won the contract for

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supplying the first of the huge generators to be installed in the American plant. The Niagara hydro-electric installation was the largest ever made up to that time, and throughout both America and Europe it was regarded as a triumph of electric engineering. It settled the question of hydraulic development of electric power, and set a pattern for future plants in every part of the world.

Westinghouse was a tremendous factor in the development of street car lines and the electrification of railroads. Among the most notable of these achievements were the electrification of the St. Clair Tunnel of the Grand Trunk Railway and the lines of the New Haven system. He was a pioneer in the designing and manufacture of gas engines and gas producers. He drilled the first wells in the Pennsylvania gas fields, and organized this industry for the distribution of cheap and abundant power to Pittsburgh and adjacent cities. One of his latest inventions was in the field of his first choice. While riding in his automobile one day, he received a severe jolt which sent him bounding to the top of the car. The result of this all-too forcible hint at a real need was the pneumatic shock absorber, now so widely used.

A man of big calibre and remarkable vision, George Westinghouse was responsible for much of the unparalleled expansion which marks the present day.

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CHAPTER XXIV

THOMAS A. EDISON

One morning in the spring of 1869, a poorly dressed, uncouth-looking young man walked into the office of the Law Gold Indicator Company on Wall Street in New York City. Without knowing it he had arrived just at the moment to be of service to the company and to secure a position which proved to be a turning-point in his own career. Through a complicated system of telegraphic indicators this company supplied to the various brokers' offices of the city the current stock quotations. The newcomer had scarcely taken a seat when the complex general instrument, which controlled the outgoing lines, suddenly came to a dead stop. Within two minutes, more than three hundred boys, one from every broker's office on the street, came swarming into the room. Each boy was yelling at the top of his voice. Pandemonium reigned. The man in charge lost his head. Dr. Law, the superintendent of the company, rushed in, frantic. In the meantime the stranger had quietly walked over to the instrument, studied its parts for a few moments and located the trouble. A contact spring had broken off and fallen between two gear wheels. He volunteered to the excited superintendent that he knew what the trouble was, and received the reply, "Fix it! Fix it! Be quick!" Deftly he removed the broken

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spring, adjusted the mechanism, and set it in operation. The boys dispersed, the eruption subsided, and Dr. Law invited the young man into his office. The youth was Thomas A. Edison, the most expert telegrapher in the Western Union system and possessed by an over-mastering ambition to become an inventor.

Dr. Law asked Edison many questions, and becoming convinced of his expert knowledge, offered to put him in charge of the office at a salary of three hundred dollars a month. Edison says, "This was such a violent jump from anything I had ever seen before, that it rather paralyzed me for a while. I thought it was too much to be lasting; but I determined to try and live up to that salary if twenty hours a day of hard work would do it."

He immediately opened a private laboratory and every minute that he could spare from his regular duties was devoted to experimental work. He frequently worked straight through the night, displaying that utter indifference to sleep that has been characteristic of his career. His immediate purpose was to improve the clumsy stock tickers then in use. Before many months he had invented and patented a number of valuable devices, including an instrument which enabled the central office to keep in perfect unison all of the tickers in the various brokers' offices of the system. At this point General Lefferts, the president of the company, called him into his office and said, "Now, young man, I want to close up the matter of your inventions. How much do you think you should receive?" Edison had intended to ask

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five thousand dollars and come down to three thousand, if necessary. But he says, "When the psychological moment arrived, I hadn't the nerve to name such a large sum, so I said: 'Well, General, suppose you make me an offer.' Then he said: 'How would forty thousand dollars strike you?' This caused me to come as near fainting as I ever got. I was afraid he would hear my heart beat. I managed to say I thought it was fair."

General Lefferts three days later closed the agreement by writing Edison a check for the amount, the first check he had ever received. Not being known at the bank, of course he could not get the check cashed at once, and on account of his deafness did not understand what the teller said to him. He left the bank feeling sure that he had been swindled. But General Lefferts arranged the matter for him. The bank teller, however, sought to have some fun at Edison's expense and paid him the whole amount in bills of small denominations. Edison had great difficulty in stowing them away in his various pockets, and the first night sat up with the money for fear it might be stolen. Upon the advice of General Lefferts, he opened a bank account and has been a capitalist ever since.

Edison began his career at Milan, Ohio, where he was born February 11, 1847. When he was seven years old, his parents moved to Port Huron, Michigan, and there he grew up. As a lad he served as newsboy and "candy butcher" on a local train of the Grand Trunk Railway. He turned the baggage car into a

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laboratory and print-shop, where he published a small sheet giving the latest news reports, which he obtained at the end of the route and from telegraph operators along the way. At one time he had five hundred subscribers and in addition sold many copies on the train. He received three cents a copy. As the cost of publication was slight, his revenue was considerable. One day, while experimenting in the laboratory, a bottle of phosphorus was jarred to the floor, and, bursting into flame, set the car on fire. In the midst of the trouble, the irate conductor appeared, and after assisting in putting out the blaze, stopped the train at the first station and put Edison off, print-shop, laboratory and all.

Soon after this event, Edison abandoned the life of a newsboy and learned telegraphy. Upon application, he was made night operator in his home town. He had pursuaded his father to let him have a laboratory on the third floor of the house, and instead of sleeping during the daytime, he persisted in experimenting. As a result, Edison repeatedly went to sleep at night and was often reprimanded by the train dispatcher. At length, his superior hit upon the plan of having Edison send him the letter A every half hour, thinking this would surely keep him awake. It worked beautifully for a few nights. But Edison saw that he must devise some scheme for getting more sleep, and he would not give up his laboratory. One evening he appeared at the station with a curious contrivance, which he connected with the telegraph instruments on the desk and the clock on the wall. He sat down to see what would

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happen. Just as he expected, when the half-hour arrived, the mechanism closed the circuit and automatically sent the letter A over the line. He waited another half hour, and, satisfied that the device was successful, went to sleep. One evening, not long after, the train dispatcher happened to be at the next station down the line. Hearing the signal come through on the dot, he called Edison, thinking he would have a chat with him. But in spite of his repeated signals no one answered. In alarm he jumped onto a handcar and hastened to the scene. Peering into the window, imagine his surprise to see Edison peacefully asleep. His first impulse was to give him a rude awakening, but, spying the contraption on the desk, he sat down to await developments. He did not have long to wait, and, although he could not help admiring Edison's ingenuity, he was compelled to dismiss him.

Edison then began the life of a wandering telegraph operator, remaining but a short time in a place and obtaining a new position as easily as he had lost the former, partly because of the great scarcity of operators in those days but largely on account of his exceptional skill as a telegrapher. He lost his second position because he allowed a train to run by and nearly caused a wreck. After serving in a number of other places, he arrived one day in Memphis, Tennessee, and applied for a job. In spite of his seedy appearance, he was assigned a desk and put on the St. Louis wire, the hardest line in the office. Pretty soon the St. Louis operator called, and the rest of the office force prepared for some fun at Edison's

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expense. It is said, "Edison threw his leg over the arm of the chair, leisurely transferred a wad of spruce gum from his pocket to his mouth, took up a pen, examined it critically, and started in about fifty words behind. He didn't stay there long, though. St. Louis let out another kink of speed and still another, and the instrument on Edison's table hummed like an old-style Singer sewing-machine. Every man in the office left his desk and gathered around the jay to see what he was doing with that electric cyclone. Well, sir, he was right on the word and taking it down in the prettiest copper-plate hand you ever saw, even crossing his 't's' and dotting his 'i's.' . . . St. Louis got tired by and by and began to slow down. Then Edison opened the key and said: 'Hello, there! when are you going to get a hustle on? This is no primer class.'"

Edison soon found it desirable to leave Memphis. He drifted to Boston. There he bought and read the whole of Faraday's works on electricity. He regarded the master of the Royal Institution as the "perfect experimenter" and took him as his model. In Boston Edison made his first invention. It was a vote-recording machine to be used in legislative halls, and its rejection by the law makers at Washington was a severe blow to his budding ambition.

The story of how Edison vanquished an army of cockroaches, while on the Boston night-shift, is worth repeating. Cockroaches in great numbers were in the habit each night of invading the table upon which the operators placed their lunches. One evening

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Edison appeared with some rolls of tinfoil and a few feet of fine copper wire. He tacked two narrow strips of tinfoil about the top of the table as closely together as possible without touching. These he connected to the large office battery of one hundred and ninety cells and awaited the onslaught of the enemy. Presently they came. The leader walked up the table leg, paused a moment at the dead-line, placed his fore feet upon the second tinfoil, and dropped to the floor electrocuted. By midnight the enemy dead formed a ring about that table thick as the hair about a barber chair.

From Boston Edison went to New York. He arrived penniless and borrowed a dollar from a friend to tide him over until he could find a job. His first meal consisted of apple dumplings and coffee, and Edison has always declared that it was the best he ever ate. It is at this point that we find him adjusting the stock ticker and entering in earnest upon the career of an inventor.

With the proceeds of his first patents, Edison opened laboratories in Newark and started upon a second period of telegraphic invention. He now employed a force of mechanics and started at the business of invention in a systematic way. One day he went into the office of the president of the Western Union, Dr. Norvin Green, in the hope of disposing of some of his new devices. But he found Dr. Green engaged in a fruitless attempt to get into communication with Albany. Something was wrong on the line. Edison said, "If I locate this trouble within two or three hours, will you take up my inventions and give them

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honest consideration?" Dr. Green replied, "I will consider your inventions if you get us out of this fix within two days." Edison immediately called Pittsburgh and asked for the best operator there. He instructed this man to call the best operator at Albany and have him telegraph down toward New York as far as possible. He did so, and within half an hour Edison reported to Dr. Green that if he would send a train to a point two miles beyond Poughkeepsie, he would find the trouble. The thing turned out as Edison said, and he won the confidence of the Western Union.

Edison's first important work for the Western Union was an improved system of duplex telegraphy by which two messages were sent over the same wire at the same time, one in each direction. He followed this with an automatic system by which he was able to send and record thirty-five hundred words per minute between New York and Philadelphia. At the receiving end the message was printed on especially prepared chemical paper invented by Edison. But it was his invention of quadruplex telegraphy which proved to be his most important contribution. By it two messages in each direction were sent simultaneously over the wire. For every telegraph wire of the Western Union it gave three "phantom wires." In this country alone it has been estimated that quadruplex has accomplished a saving of from fifteen to twenty million dollars in line construction. When he exhibited his invention to Mr. Orton, the new president of the Western Union, Edison was in dire financial straits.

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He was paying the sheriff five dollars a day to hold off a judgment which had been entered against him in a suit, and he was fearful lest he might lose his plant and machinery. But his invention worked perfectly and Mr. Orton made him an advance payment of five thousand dollars. In all he received for it thirty thousand dollars which he quickly expended on an unsatisfactory system of sextuplex telegraphy.

Turning from telegraph devices, Edison took up the newly-invented telephone. Bell had an excellent receiver but no satisfactory transmitter. He used the same instrument for both. It was not long until Edison had perfected the carbon transmitter, the same in principle as the one we use today. The Western Union was then in the telephone business. Mr. Orton sent for Edison. In the inventor's words, "He asked how much I wanted. I had made up my mind that it was certainly worth twenty-five thousand dollars. . . . Still it had been an easy job, and only required a few months, and I felt a little shaky and uncertain. So I asked him to make me an offer. He promptly said he would give me one hundred thousand dollars. 'All right,' I said. 'It is yours on one condition, and that is that you do not pay it all at once, but pay me at the rate of six thousand dollars per year for seventeen years — the life of the patent." To this proposition Mr. Orton readily assented.

About this time, at the request of Mr. Orton, Edison invented what he called the "electromotograph," an instrument for operating by a different method from that then in use, the relay and sounder of a telegraph

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line. Again he was paid one hundred thousand dollars, on the same terms as the previous payment. One day he received a cablegram offering him "thirty thousand" for his English rights in this invention. He immediately cabled his acceptance, thinking the offer was for thirty thousand dollars. Much to his astonishment, when the draft came it was for thirty thousand pounds.

From his experiments on the telephone Edison had learned the property of a diaphragm to take up sound vibrations. This was the clew that led him to the invention of the phonograph. He made a rough sketch of the model and handed it to John Krusei, one of his master workmen, to construct. In thirty hours of continuous labor Krusei produced the model. Standing there in his laboratory with his assistants about him, Edison slowly turned the handle of the machine and spoke into the receiver the first verse of "Mary had a little lamb." Then the cylinder was returned to the starting point and there came back like an echo the words of this nursery rhyme in the familiar tones of Mr. Edison. The next morning he took it into the office of the Scientific American and created nothing less than a sensation. Operating in that crude model was the principle of the highly perfected talking machine of today. The rest was merely a matter of development and mechanical detail. Probably in no other invention has Edison contributed more largely to human happiness.

But it is as the inventor of the electric light that Edison will be longest known. It was in 1877 that he

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completed his early work on the phonograph. In the following year, at the request of Professor Barker of Pennsylvania University, Edison began to work on the problem of "sub-dividing the electric light." Powerful arc lights were then in use on a limited scale, but they were too bright, too expensive, and too troublesome for ordinary service. With that lightning-like perception so characteristic of the man, Edison saw what was needed. There was born in his mind the vision of the small incandescent lamp for factory, office, and home. A small exhausted glass globe with a slender filament heated to incandescence by the electric current — that was his ideal. But the substance for the filament proved the baffling part of the problem. His first experiments were with fine platinum wire. But it was both expensive and unsatisfactory. Then he tried every conceivable substance that he thought might serve his purpose. Still the search was without result. But Edison knew that somewhere the ideal material existed. It was merely a matter of finding it. One evening, as he sat in his laboratory musing over the problem, his hand accidentally came in contact with a piece of lampblack lying upon the table. Listlessly he picked it up and rolled it between his fingers into a long, thin filament. Then, seeing what he had done, the idea flashed into his mind that here might be the long-sought substance. With infinite difficulty, he and an assistant mounted it in a globe, exhausted the air, and turned on the current. It glowed with a beautiful soft light for a few moments and then flashed out. Still its life

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had been long enough to show Edison that he was at last on the right track.

He sent out immediately for a reel of cotton thread, and cutting off a suitable length, bent it horseshoe shape, clamped it in a nickel mold, and placed the mold in a muffle furnace. After five hours, he removed the mold, allowed it to cool, and took out the precious filament. But it instantly broke. This process was repeated many times. Not until the evening of the third day was a filament successfully mounted, the air exhausted, and the current turned on. The light that greeted the gaze of the experimenters seemed the most beautiful they had ever seen. Oblivious of their seventy-two hours without sleep, Edison and his assistant, Charles Bachelor, sat there and watched that first incandescent lamp for forty hours more.

Edison now knew that carbon was the ideal material, but what variety was best? For weeks he carbonized and tested every carbon substance imaginable. One day, sitting at his desk, his eyes rested upon a bamboo fan. He could think of nothing else that had not been tried. Tearing loose a fiber, he carbonized and mounted it. Upon turning on the current, it seemed to answer every requirement. It was by far the most satisfactory that had been tested. Still Edison felt certain that there must be some particular species of bamboo that was better than every other for his purpose. Determined to find it, he ransacked the earth. Men were sent to the Malay Peninsula, China, Japan, the West Indian islands, Mexico, Ceylon, India,

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and South America. He carbonized more than six thousand varieties, and at length, from the jungles of the Amazon, he obtained perfect specimens. He then engaged a native of Japan to grow this kind of bamboo for him. The hunt had cost him one hundred thousand dollars, but Edison never counted the cost when the success of his inventions was at stake.

He continued to improve the incandescent lamp for many years. His early exhibitions of electric lighting at Menlo Park, whither he had moved his laboratories, were the most talked-of scientific events of the day. Excursions were run from New York to see this brilliant spectacle of small electric lights hanging like candles from the limbs of the trees along the streets of the New Jersey town. But Edison saw that if his new lamp were to become anything more than an interesting experiment, there must be central stations for the manufacture and distribution of electric power. But where were the dynamos and engines, the fuses, switches, and meters necessary for this work? They did not exist. Edison was compelled to create them. He organized the Edison Electric Light Company, and on Pearl Street in lower New York built the world's first central station. It was a Herculean task. Edison scarcely rested, for weeks at a time. Single-handed he created a new industry. Until electric lighting came, dynamos had had but little practical use. Edison's pioneer work in perfecting them was fundamental to future progress. At this time, too, he did much early work on electric motors for street car locomotion. The first electric lighting plants for

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hotels, ships, and public buildings were made in Edison's factories. At Harrison, New Jersey, he started the biggest incandescent lamp works in the world. Let us never forget that the artificial sunshine that floods our homes, and public and private buildings, we owe to Edison, who counted drudgery nothing if he might thereby serve the world's needs.

But Edison worked in numerous fields. Doubtless many people would count the invention of the moving picture machine his crowning achievement. Certainly few other inventions have had greater educational influence or have offered more of recreation to the masses than the cinema film. As early as 1912 he combined the moving picture and talking machines, and predicted that the time was not far distant when grand opera would be presented in this manner.

Edison invented a magnetic ore separator and new processes for making Portland Cement. But probably his greatest contribution in recent years has been the alkaline storage cell. Before giving it to the public he spent eight years of research and made nine thousand experiments. Experience has shown that the cell is fool-proof. It has abundantly earned the right to Edison's description, "Built like a watch; rugged as a battleship." In testing the battery he sent out a number of electric automobiles with instructions that each should make a hundred miles a day over the roughest roads to be found. The drivers were told that when a particularly bad piece of road was encountered the day's mileage should be made by repeatedly going

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back and forth over that stretch. One by one the cars returned, racked to pieces, loose in every joint, fit only for the scrap-heap, but the storage cells were in as good condition as on the day they left the factory.

During the war, when we were cut off from German coal tar products, Edison devised a process for making synthetic carbolic acid. Working alternate shifts of men twenty-four hours a day, he completed a plant for this purpose in eighteen days, and within four weeks from the date of opening he was producing one ton of the chemical per day. His great works at West Orange, New Jersey, burned in 1914. Within thirty-six hours he had a new fireproof structure under way. He also built and operated benzol and other chemical plants during the war. He was made president of the Naval Consulting Board in 1915 and made many war inventions for the government. In all, Edison took out well over a thousand patents.

Edison received many medals from his own and other countries. He was signally honored by the French Government in being elected Chevalier, Officer, and afterwards Commander of the Legion of Honor. He was a veritable human dynamo. He always said that "genius is one per cent inspiration and ninety-nine per cent perspiration." His manifold lines of activity constituted a whole educational institution in themselves. No other man, past or present, gave so tremendous an example of the possibilities of applied science. His many inventions touch life at so many points and his name is so closely identified with the

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big scientific achievements of the last several decades that his fame can never die. There will always be but one Edison in the annals of science.

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CHAPTER XXV

ALEXANDER GRAHAM BELL

Seated in Madison Square Garden, New York City, on Armistice Day, 1921, the author "witnessed" the impressive ceremonies in remembrance of America's Unknown Soldier at Arlington, Virginia. "Impossible," it seems, and yet true. Even more, at the same time an audience of twenty thousand in San Francisco "stood beside the casket" of America's hero. Newly invented loud-speaking telephones caught the voices, the music, and the peal of guns at Arlington and amplified them for reverent thousands on either ocean-side. Every word was clear and distinct. Not a syllable was blurred. The voice waves were so magnified by new electrical devices that every member of those vast audiences heard as well as they who stood within the marble amphitheater at Arlington itself.

At fifteen minutes before twelve, from amplifying projectors suspended from the roof of the Garden and from others over the entrance outside, came a clear resonant voice that could be heard by everyone of the assembled thousands. It said that President and Mrs. Harding were entering the amphitheater at Arlington. It told of the beauty of the scene, with the Potomac and the city of Washington in the distance and the white

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marble colonnades glistening in the sunlight. In imagination we saw the foreign diplomats, the judges of the Supreme Court, the members of Congress, the thousands of troops, the gold-star mothers, and the silent multitudes gathering to pay the nation's tribute to her heroic dead. There was an interval of silence. The vast audience scarcely breathed. Then the spell was broken by the strains of the National Anthem, played by the United States Marine Band at Arlington, but heard so perfectly and in such volume that it seemed as if the band must be within the Garden itself.

Word for word we listened to the service. Secretary of War Weeks introduced President Harding, and we heard his voice, rich and full, say, "We are met today to pay an impersonal tribute. The name of him whose body lies before us took flight with his imperishable soul. We know not whence he came, but only that his death marks him with the everlasting glory of an American dying for his country." As the President pinned to the casket the Distinguished Service Cross and the Medal of Congress, we heard him say, "Won in mortality, to be worn in immortality." And so on to the peals of artillery re-echoing from the Virginia hills, and the sounding of taps.

Amplifying projectors were also used at Arlington to enable the hundred thousand gathered on the slopes about the cemetery to hear the addresses and the music. This transmission was by wire, not by radio. The invention of the loud-speaking telephone marks

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an epoch in the art of communication and the power of human speech. This demonstration showed that it is only a matter of putting up sufficient apparatus to enable the President or any other speaker to be heard in every city and hamlet from ocean to ocean and from the Gulf to the Lakes. An individual speaker may fill this broad land of ours with the sound waves of his voice. And Alexander Graham Bell, who invented the telephone and heard its first feeble cry, was still at work in his laboratory.

But let us witness the birth of the telephone in a Boston attic nearly a half century before. On the afternoon of June 2, 1875, in a hot upper room of Williams' Electrical Shop, at 109 Court Street, Bell and an apprentice lad, Thomas A. Watson, were struggling with a balky piece of electrical mechanism. For many weeks they had been engaged on the invention of a musical telegraph by which they hoped to be able to send a number of messages over a single wire at the same time. Yet despite the expenditure of a wealth of thought and effort the device stubbornly refused to work. And then, without knowing it, on that memorable afternoon they were to make history. What happened we shall let Watson tell.

"On the afternoon of June 2, 1875, we were hard at work on the same old job, testing some modification of the instruments. Things were badly out of tune that afternoon in that hot garret, not only the instruments, but, I fancy, my enthusiasm and my temper, though Bell was as energetic as ever. I had charge of the transmitters as usual, setting them squealing one

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after the other, while Bell was retuning the receiver springs one by one, pressing them against his ear as I have described. One of the transmitter springs I was attending to stopped vibrating and I plucked it to start it again. It didn't start and I kept on plucking it, when suddenly I heard a shout from Bell in the next room, and then out he came with a rush, demanding, 'What did you do then? Don't change anything. Let me see!' I showed him. It was very simple. The make-and-break points of the transmitter spring I was trying to start had become welded together, so that when I snapped the spring the circuit had remained unbroken while that spring of magnetized steel, by its vibration over the pole of its magnet, was generating that marvelous conception of Bell's — a current of electricity that varied in intensity precisely as the air was varying in density within hearing distance of that spring. That undulatory current had passed through the connecting wire to the distant receiver which, fortunately, was a mechanism that could transform that current back into an extremely faint echo of the sound of the vibrating spring that had generated it, but, what was still more fortunate, the right man had that mechanism at his ear during that fleeting moment, and instantly recognized the transcendent importance of that faint sound thus electrically transmitted."

In that moment Bell knew that the telephone was no longer a dream, but an accomplished fact. Complete success was now only a matter of detail. Yet the inventors worked forty weeks before they made

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their telephone talk. Over and over on that first afternoon they verified the discovery. Then Bell gave Watson directions for making the first instrument. Watson says,

"I was to mount a small drumhead of goldbeater's skin over one of the receivers, join the center of the drumhead to the free end of the receiver spring and arrange a mouthpiece to talk into. His idea was to force the steel spring to follow the vocal vibrations and generate a current of electricity that would vary in intensity as the air varies in density during the utterance of speech sounds. I followed these directions and had the instrument ready for its trial the very next day. . . . I made every part of that first telephone myself, but I didn't realize while I was working on it what a tremendously important piece of work I was doing."

Watson stretched a line down two flights of stairs from the attic to the main floor of Williams' shop. But shout loudly as he might, Watson could not make Bell hear. Watson, however, could hear Bell's voice and almost catch the words. Then on March 10, 1876, Watson heard Bell say, "Mr. Watson, please come here, I want you." Watson says, "Perhaps, if Mr. Bell had realized that he was about to make a bit of history, he would have been prepared with a more sounding and interesting sentence." Success now became rapid and certain. In a few weeks Bell's telephone was ready for public demonstration. The Centennial Exposition, then opening in Philadelphia, afforded just the opportunity Bell needed.

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Before we proceed with the introduction of the telephone to the public, let us sketch briefly Bell's early career. He was a young Scotsman who had come to this country to seek health and fortune in a new land. Watson describes him at that time as "a tall, slender, quick-motioned man with pale face, black side whiskers, and drooping mustache, big nose and high sloping forehead crowned with bushy, jet black hair." For generations his family had been interested in human speech. Bell himself was a master of acoustics and an able elocutionist. On a trip to London, he had learned through Sir Charles Wheatstone, the inventor of the English telegraph, that the German physicist Helmholtz had vibrated tuning forks by means of electromagnets. This gave Bell the idea of his musical telegraph, and started him on the path of invention which ended with the telephone. "Why," he asked, "cannot a vibrating reed or fork be made to vary an electric current so as to reproduce sound? Should it not be possible to send as many messages over a single wire as there are notes on a piano?"

Coming to Boston, Bell began to teach deaf-mutes by a system of visible speech invented by his father. His success in this work won for him a professorship in Boston University. For a time he almost forgot the musical telegraph. Then he went to live in the home of Thomas Sanders at Salem. Here he gave private lessons to Georgie Sanders, a little deaf-mute, and was allowed the privilege of turning the basement of the house into a laboratory. With this opportunity the idea of his invention soon crowded every other

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thought from his mind. There also came to him at this time another private pupil, Mabel Hubbard, who four years later was to become his wife, and whose father, Gardiner Hubbard, a prominent lawyer of Boston, was to have a large part in the commercial success of the telephone.

Using a speaking trumpet as transmitter and a harp for a receiver, Bell discovered that he could make sound waves plainly visible by speaking against a flexible membrane, to which he had attached a short stylus. Substituting a human ear for the membrane, he was able to make the spoken voice trace a record of its vibrations in beautiful curves on smoked glass. This was the mechanism about which his telephone grew. "Why," he asked, "should not a vibrating iron disc set an iron rod or an electrified wire into vibration?" And again, he reasoned, "If I can make a deaf-mute talk, I can make iron talk." A visit to the venerable Joseph Henry at this time proved a wonderful stimulus to his endeavors. He had forsaken his professorship in the university, and only his two private pupils remained. Sanders and Hubbard financed his experimental work, but poverty and hardship dogged his life. Gradually the idea of an actual talking telephone crowded the musical telegraph out of his mind. But his financial backers refused further assistance, should he abandon his original purpose. Therefore, he divided his time between the two, and it was while working on the musical telegraph that the discovery was made which led to the telephone.

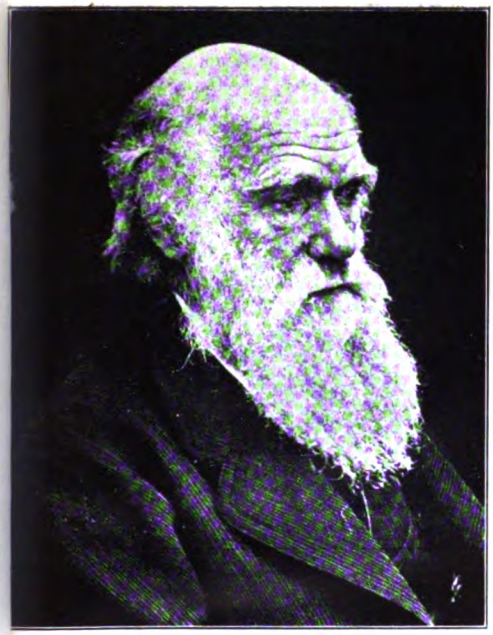
At the Centennial, seated at a table in an out-of-

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the-way corner of the Educational Building, where he had his exhibit and a short line, Bell patiently awaited the visit of the judges. At last they came. It was just at dusk. They were tired and hungry after a long day of inspection. No one was interested in his invention. "Of what use was the toy anyway? What did it matter if speech could be sent over a wire?" One or two approached the table, fingered his instruments listlessly, and the judges were about to pass on. Then a dramatic thing happened. Just at that moment, as though the scene had been transferred to fairy land, a prince, followed by a gaily attired company of courtiers, appeared. Rushing up to Bell the prince greeted him with great fervor. He was Dom Pedro, the young emperor of Brazil. Dom Pedro had visited Bell's classes for deaf mutes on an earlier trip to this country and remembered the young master of acoustics. The emperor was all interest. Bell quickly explained his invention. There in the twilight, with the awed and silent judges as an audience, Dom Pedro stepped to the opposite end of the line. Placing the receiver to his ear, he listened as Bell spoke. In amazement he dropped the instrument, exclaiming, "My God, it talks!"

Skepticism was at an end. Weariness and hunger were forgotten. One by one the judges came forward, each in his turn to test for himself this latest miracle of invention. Among them were Joseph Henry and Sir William Thomson. The hero of the Atlantic Cable declared it to be "the most wonderful thing he had seen in America." Over night Bell had leaped to

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DARWIN



PASTEUR



HENRY



BESSEMER

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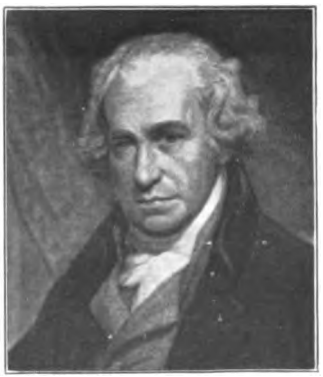
ALVAN G. CLARK



HOLLAND



LAKE



WATT



FULTON

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world fame. The next morning, his telephone was brought out from its obscure corner and given the most conspicuous place at the Exposition.

Still the public was indifferent to Bell's invention. Its interest was only that of curiosity. No one could see any use for it. Bell was in a position similar to that of Morse a generation before. He might have won fame, but no fortune seemed to await him. Then under the business management of Hubbard, Bell and Watson began to give lectures accompanied by demonstrations. It was the first "broadcasting" ever done in any country. The first demonstration was given before the Essex Institute of Salem. Bell appeared before the Salem audience, and Watson remained in the Boston laboratory to supply the entertainment. Bell described his invention, and over a borrowed set of telegraph wires Watson transmitted music from various instruments, even singing favorite melodies himself. The audience was delighted. Newspapers featured the event, and invitations to repeat the lecture came like a flood. With the proceeds of these Bell married and sailed to Europe on his wedding trip.

In his absence Hubbard organized the "Bell Telephone Association." But progress was slow. A few burglar alarm systems were established. Small exchanges in New York, New Haven, Bridgeport, and Philadelphia appeared. The demand for telephones increased. Then an important event occurred in New York. One of the large Wall Street patrons of the Western Union asked that the printing telegraphs be removed and telephones substituted. Bell had already

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offered his invention to this organization, and it had been contemptuously refused. But now the Western Union awoke. Organizing the "American Speaking Telephone Company," with a capital of three hundred thousand dollars, they attempted to dominate the telephone field. But Bell won a decisive victory in the courts, and the two companies decided to divide between them the field of electric communication, the Western Union retaining the telegraph rights and the new domain of the telephone art going to the Bell Company.

The immediate result of this victory was to send the Bell stock to one thousand dollars a share. The original promoters, Bell, Watson, and Sanders at this point sold out their interests, and the development of the telephone passed into other hands. Each received a comfortable fortune and the recognition that was his due.

Bell's patent has been described as the "most valuable single patent that was ever issued." And no patent has been more bitterly contested. In all, Bell and his company were compelled to fight six hundred suits, brought by a host of pretenders to the great invention. But Bell's rights were always sustained by the courts. His most formidable competitor was Elisha Gray. Gray's partner once said, "Of all the men who didn't invent the telephone, Gray was the nearest." The one incontestable answer to all these claims is that no one but Bell, in court or out, produced a talking telephone.

The work of telephone development is a romance in

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itself. Berliner, Edison, Thomas Hughes, Francis Blake, and Rev. Henry Hunnings contributed to the invention of the transmitter. Theodore N. Vail supplied the executive ability. Charles E. Scribner and Col. John J. Carty were the pioneers in switchboard construction. Colonel Carty, now vice-president of the American Telephone and Telegraph Company, is the founder of the profession of telephone engineering. He substituted a metallic return wire for the earth, and thereby banished the babble of weird underground noises that in those early days played over the telephone circuits. In New York he put the maze of overhead wires into underground cables. He invented the bridging bell by which several subscribers may be put on a single wire, and substituted the central battery system for the individual batteries along the line. Under his direction the two oceans have been placed in telephonic communication, and wireless telephony on a large scale has become a fact. Important factors in the success of transcontinental telephony were the loading coil of Professor Michael Pupin of Columbia University, and the audion bulb amplifier invented by Dr. Lee De Forest.

In all of this development Bell was only an interested observer. But in 1915 Bell and Watson played important rôles in a great triumph of telephone engineering. On January 25 of that year the transcontinental line was opened. It is three thousand three hundred ninety miles long and contains two thousand nine hundred sixty tons of copper. The line is strung on one hundred thirty thousand poles and crosses

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thirteen states. At frequent intervals vacuum tube amplifiers intensify the feeble talking currents and relay them across the continent.

As on that other historic occasion in 1876, Bell in New York, speaking into an exact reproduction of his original instrument said to Watson in San Francisco, "Mr. Watson, please come here, I want you." And Watson answered, "It would take me a week now." As easily and distinctly as though they had been in adjoining rooms, these men, who spoke and heard the first message of the baby telephone, conversed with each other across the continent. A wonderful sequel to a romantic chapter of human progress! But still the telephone romance did not end; possibly it never will.

In the spring of 1921 Colonel Carty opened telephone communication by cable, wire, and wireless from Havana, Cuba, to Catilina island, off the coast of southern California, a distance of five thousand and five hundred miles. Multiplex telephony has made possible five conversations over the same wire at the same time. During the Great War, Secretary Daniels, speaking into an ordinary telephone transmitter, conversed by wire and wireless with every naval station from ocean to ocean and from the Gulf to the Lakes.

Over the "talk tracks" of the nation, the American people converse with each other at the rate of eighteen billion, two hundred and fifty million completed telephone conversations per year. In addition there are three billion conversations that are originated but not completed. In New York City, from 10 A.M. to

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11 A.M., the busiest hour in the day, nearly a half million calls are received and answered by the operators in the various exchanges of the city. In the metropolis alone there are a million telephones and three and a half million miles of wire.

Not long before his death in August of 1922, Bell said,

"I now realize that I never should have invented the telephone if I had been an electrician. What electrician would have been so foolish as to try any such thing? The advantage I had was that sound had been the study of my life — the study of vibrations. I confess I do not understand tonight how a man can talk in Arlington across the river from Washington, and a man in the Eiffel Tower in Paris hear him. I dare admit I blazed the way, but the great discoveries and development that followed called for the correlation of many minds."

Bell was a true scientist and inventor to the end of his days. He contributed much to our knowledge of aeronautics, and he regarded the photophone, upon which he worked in his declining years, as perhaps his greatest invention. His life was happy and fortunate. It has seldom been given to any man to witness so sweeping a conquest by the original product of his brain and hand.

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CHAPTER XXVI

GUGLIELMO MARCONI

Early in December, 1901, a young Irish-Italian, Guglielmo Marconi, crossed the Atlantic from England to Newfoundland. For a week he and two assistants busied themselves in fruitless endeavors to get aloft several huge kites. The first, a hexagonal contrivance of bamboo and silk, nine feet high, broke loose from its fastenings and was swept out to sea. Others suffered a similar fate. A fourteen-foot hydrogen balloon, tugging at its moorings, snapped the tie-wires and was never seen again. At length on December 12, from the foot of Cabot Tower on Signal Hill, in the teeth of a fierce gale, they managed to get a kite up four hundred feet and hold it. A wire led from the kite down to a pole and through a window into an upper room of an old barracks, where sat two men, Mr. Marconi and Mr. Kemp. Some simple apparatus connected the aerial with a ground wire and to a telephone receiver. The day was raw and cold. Three hundred feet below, the surf broke in a mighty roar against the foot of the cliff, and beyond rolled two thousand miles of sea.

Presently Marconi, who had been listening for half an hour without result, passed the telephone receiver to Kemp. In a moment came the tapping of the decoherer. Something was happening. Still no signal.

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Would the test fail? The little room with its two occupants was tense with expectancy. Suddenly there came clearly and unmistakably the three clicks, or dots, of the letter S. Marconi listened. Yes, there could be no doubt. The ether waves had carried across the Atlantic, and transoceanic wireless was no longer a dream, but a demonstrated fact.

Yet in this moment of triumph Marconi did not feel elated. A strange dejection possessed his mind. What evidence had he of his accomplishment? There was no record of his success. Only the repeated verifications of the incoming signals by himself and his friend told the tale. Would the world believe him? No newspaper reporters had been present to corroborate and herald the event. For two days Marconi hesitated before giving the news to the public. Then he dispatched a cablegram to England and awaited the result. It came with wonderful swiftness. The first mild wave of doubt was quickly swept away by a flood tide of generous confidence and unbounded enthusiasm. Wireless telegraphy was not new, and the recently discovered marvels of the X-Ray and radioactivity had paved the way for any surprise. But more than this, Marconi had never deceived the public. And he had already accomplished much.

At Poldhu on the coast of Cornwall, England, Marconi had established a powerful sending station. Before crossing to Newfoundland, he had instructed his operator at Poldhu to send the letter S every day, beginning at 12.30, Newfoundland time. Among the little group of observers that gathered about the

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Cornwall station, great was the excitement and suspense. From the aerial, supported by a ring of huge masts two hundred and ten feet high, the three dots of the letter S were repeatedly sent forth, accompanied by the blinding flashes and resultant thunder of the powerful transformer that produced them. The ether waves, speeding outward with the velocity of light, had crossed the ocean and had been detected by an ordinary telephone receiver. "I believed from the first," Marconi said, "that I would be successful in getting signals across the Atlantic."

Marconi was not the first to experiment with wireless waves. Much had been accomplished before his time. Indeed, had it not been for the researches of a number of pioneers of the radio art, Marconi's inventions might still be in the future. As early as 1842, Morse, during those dark years of patient waiting for the assembling of a Congress favorable to his project, succeeded in telegraphing across a canal with only the water to carry his signals. Bell contributed the telephone receiver. Professor Trowbridge, of Harvard, showed that alternating current signals might be sent through the earth and detected by grounding the terminals of a telephone circuit. He was also able to send signals through the ether from one huge coil to another, but the distances were short and the current requirements large. In 1879, Professor Dolbear, of Tufts College, made use of aerial antennae and invented a static telephone, which to a remarkable degree anticipated wireless telegraphy. In the early eighties, Edison patented a system of telegraphy

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by which ether waves sent from short aerials on the top of a moving train were caught by the adjacent telegraph wires and carried to any station on the line. About this time Sir William Preece and A. W. Heaviside, in England, signaled across a space of ten miles by means of parallel telegraph wires. By laying wires on the ground, and in mines, they were able to communicate with miners at a depth of four hundred feet. Communication with the light station on Fastnet Rock seven miles off the coast of Ireland had been repeatedly interrupted by the breaking of the cable. Preece and Heaviside cut the cable at either end and anchored it to the bottom. Then, by submerging telegraph wires from each station, service was maintained without difficulty. So in this, and in Edison's experiments, "wired wireless" was anticipated by nearly forty years.

Yet wireless telegraphy would have been only a dream had it not been for the discoveries of a young German physicist named Heinrich Hertz, a former pupil of Helmholtz and professor of physics at Karlsruhe. Twenty years before, the eminent British physicist, Clerk-Maxwell, had demonstrated mathematically that light is due to electromagnetic vibrations in the ether. But not being a scientific experimenter, he had been unable to prove his theory. It remained for Hertz to show that electrical waves may be produced in the ether having all the fundamental properties of light waves, and differing from them only in pitch and penetrating power.

One day in 1886 this young German scientist was

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experimenting in his laboratory with two short flat coils of insulated wire. Much to his surprise, he discovered that when a Leyden jar was discharged through one coil currents were induced in the other coil. Further investigation showed that this occurred only when a small spark gap was left in the first coil. He soon found that the discharge of the Leyden jar would induce currents in the second coil, even when it was carried to a considerable distance from the *exciter*, as he termed his transmitting apparatus. Leaving a small gap between the ends of the wire in his receiving coil, Hertz obtained a spark at this gap, whenever the discharge was made across the terminals of the sending coil. By varying the length of the gap, he discovered that the receiving coil could be tuned into sympathy with the sending coil. At a certain length the spark was always brightest. In that simple apparatus was operating the first real hundred per cent wireless telegraph set. Yet the world had not long been ready for this discovery. Wire telegraphy was only a generation old, and telephony was still in its infancy. Indeed, Sir Oliver Lodge, who several years before had produced wireless waves, stated that he could see no use for wireless telegraphy at that time.

Hertz continued his experiments, but he soon substituted an induction coil for the Leyden jar. To the terminals of the spark gap he connected large squares of zinc to serve as radiators of the electric energy. A single loop of wire having an adjustable spark gap constituted his receiver. By means of parabolic mirrors and other devices, he was able to demonstrate

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that these ether waves may be reflected, refracted, and polarized and therefore possess all the properties of light and radiant heat waves. He measured their velocity and found it to be that of light, but their lengths proved to be much greater.

Another discovery essential to Marconi's success was made about 1890 by Professor E. Branly of Paris. Professor Branly had learned that, if a small glass tube loosely filled with metal filings were placed in circuit with a battery and an electric bell, the current-flow would not be sufficient to ring the bell. When, however, waves from a Hertzian oscillator were allowed to pass through the filings, he found that the metal particles would "cohere," or arrange themselves in a path of such small resistance as to permit the ringing of the bell. This constituted a detector for these new-found waves, and was just the device necessary for further progress. Professor A. Popoff of Russia first made use of it to detect the electro-magnetic waves from lightning discharges.

Now we come to the early work of Marconi. Marconi was born at Villa Griffone near Bologna, Italy, April 25, 1874. His father was a landed proprietor of Italy and his mother came from a well known and influential family of Dublin. When Hertz began his famous experiments in 1886, Marconi was but twelve years old. At the time he was a pupil of Professor Righi, an Italian scientist of some note and an early investigator of the Hertzian waves. With his master, even at this early age, Marconi repeated all of the published experiments. Having a strong natural

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bent toward scientific work, he took the keenest interest in this new field of wireless waves. Seldom has the fascination of a scientific discovery gripped one so strongly as did the possibilities of wireless communication grip young Marconi. Only a lad, he was the first of that vast army of young radio enthusiasts in his own and other lands.

Surely, he thought, others must see the future promise of these new waves. He waited patiently for news of further discoveries by the learned scientists in their well-equipped laboratories. But he waited in vain. The Hertzian waves were only another scientific curiosity, a beautiful addition to the realm of abstract physical truth. That they might have practical application to the needs of a busy world, no one saw. But this young Irish-Italian had caught a vision of the future, strangely enough denied to men of broader training, and he began to experiment for himself.

Dreaming dreams of how these magic waves, traveling with the velocity of light, might bear messages from continent to continent and from ship to ship, Marconi attacked the problem with all the enthusiasm of youth. On opposite sides of his father's garden he set up poles to which he attached plates of tin to serve as aerials. To the sending aerial he connected one terminal of his induction coil. The other terminal he grounded. This was something new. Marconi did not then know that these ether waves travel with their feet, so to speak, upon the ground. But the idea was a happy one and a secret of his early success. It in-

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creased many times the capacity of his oscillator to produce and radiate electromagnetic waves. Using a simple spark-gap resonator, to which he connected the receiving aerial, he was in a short time able to send and receive messages over a distance of a few hundred feet. Others had done as much, but Marconi's goal was something more than sending messages a few hundred feet.

It did not take Marconi long to discover that the receiving instrument was the critical part of his mechanism. For Hertz' resonator he substituted the Branly coherer. But he improved it. Between silver plugs inserted in a small glass tube, he placed a mixture of nickel and silver filings. This he connected in circuit with the aerial, an ordinary telegraph relay, and a cell. To jar the filings apart and make them nonconducting after the passage of each wave train, Marconi devised an automatic tapper, or decoherer. The ether waves of an incoming signal were caught by the aerial, passed through the coherer and down to the earth. This did three things. It made a conductor of the metal filings; it closed the local telegraph circuit and gave the regular Morse signal; and it closed the decoherer circuit, thus putting the filings in a nonconducting condition again, leaving the mechanism ready for the next set of waves. Marconi also discovered that the taller the aerial, the greater the range of transmission and reception. Within two years he was sending messages over distances of several miles.

Marconi proceeded to England. There he was cordially received by Sir William Preece, and through the

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latter's influence was given permission to set up his instruments in the Post Office Building in London. He quickly scored an initial success. Thick walls and an intervening roof proved no obstacle to the passage of his signals. Transmission between stations two miles apart was equally successful. He wirelessed messages from the Isle of Wight to the mainland. Upon returning to Italy he borrowed a warship from the government and succeeded in sending messages at varying distances from ship to shore. Wireless reports of the annual Kingstown regatta for a Dublin paper made a strong popular appeal, as did also wireless communication between Queen Victoria and her son, the Prince of Wales, who was ill upon his yacht off the English coast. In the spring of 1899, from aerials one hundred and fifty feet tall, Marconi communicated across the English Channel. The new wireless telegraph saved a ship in distress on a rock-bound portion of the North Sea coast. Light-ships were early equipped with it. The movements of British warships in a sham battle were directed completely by wireless control. By 1900 Marconi was sending wireless signals over the greater part of Europe. We have already seen that in the following year he had brought America within his range.

In the meantime the British Admiralty had paid him one hundred thousand dollars for the use of his invention in the navy. Other nations also licensed the use of this new method of communication, and the commercial development of the radio art has proved a still richer reward to the young inventor. The

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poverty which so often accompanies the early years of an inventor's career did not touch Marconi. True, he met with opposition in abundance. People scoffed at the idea of talking through empty space. But developments in the radio art came with such bewildering rapidity that ridicule turned to admiration. The prediction that the ether would be choked with a mystic maze of criss-cross messages was answered by Marconi's application of the principle of selective tuning, so familiar now to every follower of this fascinating pastime of "listening-in on the universe." Wireless in the hands of Marconi soon demonstrated its ability to serve the world. Numerous rescues of imperiled ships, especially that of the *Republic* in 1908 and the *Titanic* four years later, are notable examples.

Marconi's most important contributions to wireless ceased with his achievement of transatlantic communication. But he never abandoned his experiments, and as an organizer he was a tremendous factor in the commercial development of the art. A modest man, reserved and cold in temperament, more English than Italian, Marconi never boasted of his successes. In 1914, he was awarded the Franklin Medal in this country, and was honored by his own and other governments. In the World War, he served as an officer in the Italian army. One of Marconi's most spectacular efforts was his attempt to get in communication with the "inhabitants of Mars," and thus make of our sister planet a next-door neighbor. It would be a rash individual, who, in view of the rapid dwindling of our giant earth to a pygmy-dwarf,

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should declare that this may never happen. Seemingly impassable voids of space may yet be bridged by radio.

The meteoric rise of wireless in the hands of a host of other inventors has been the marvel of recent times, and even yet the wonder of it has not ceased. Each week brings some new triumph. It is actually true that it has not been commercially profitable to keep pace with the progress of invention. At the present moment, the manufacturers of wireless equipment are finding it necessary, for economic reasons, to withhold temporarily two vastly superior detectors of the ether waves.

The wireless apparatus of today bears little resemblance to that with which Marconi startled the world. The coherer was quickly superseded by the crystal detector, which permits waves to pass through it in but one direction, and converts the oscillating electric current of the antennae into a direct pulsating current, capable of producing audible signals in an ordinary telephone receiver. But the marvel of wireless has been the vacuum tube detector and amplifier. It not only is a wonderfully sensitive detector, but a generator of wireless waves as well. It has taken the place of Marconi's antiquated induction coil. The highly developed radio generators and transformers which but yesterday were marvels of invention are today little more than junk. Five of these vacuum tube oscillators, not many times larger than as many electric lamps, were recently substituted for the huge generators employed in the transatlantic service. The

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vacuum tube has harnessed the electrons, those infinitesimal particles of negative electricity which we regard now as one of the two ultimate constituents of matter, to generate, receive, and amplify the ether waves. It may yet give us that dream of modern scientists, the wireless transmission of electric power. This little giant of electric progress has been the product of a multitude of minds. Edison made the initial discovery. Dr. Lee DeForest, an eminent American pioneer of the radio art, took the Fleming valve and converted it into the first real vacuum tube detector. From that point it has been developed by the engineers of the American Telephone and Telegraph Company and of the General Electric Company into the marvelously efficient and many-sided instrument which we know today.

What the radio art holds for the future no man can say. In the World War it was of paramount importance. Now, in the pursuits of peace and in the recreation of people everywhere, it is performing a vastly greater service. The eager, earnest devotion of an Italian youth to a great idea has borne fruit beyond all expectation, and the end is still in the distant future.

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CHAPTER XXVII

THE INVENTORS OF THE SUBMARINE

JOHN P. HOLLAND

The submarine, as we know it, is a modern invention and, like the airplane, a product of American ingenuity. Such a craft had been the dream of many men for more than two centuries before its actual appearance as a formidable instrument of war. Probably the first of these early boats was made by the Dutchman Van Drebble about the beginning of the seventeenth century. During the War of Independence an American inventor, David Bushnell, built a real submarine. It stood on end, carried a crew of one, was operated by man-power, and could remain submerged for half-an-hour. Its only exploit was an unsuccessful attempt to sink the *Eagle*, a British man-of-war lying in New York Harbor. The next man to turn his attention to underwater craft was Robert Fulton, the inventor of the steamboat. But he could never interest his own or foreign governments in these miniature submarines and, much to his disappointment, was compelled to abandon the enterprise. During the Civil War a diminutive underwater boat, called a "David" in distinction from the "Goliaths" of the northern navy, succeeded in sinking the large battleship *Housatonic* lying in Charleston Harbor.

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After the Civil War, Thorsten Nordenfelt, a Swedish inventor, and Gustave Zede, a Frenchman, built more or less successful submarines. Still it was not until the work of the Irish-American inventor, John P. Holland, that the really modern submarine had its beginning.

On September 22, 1914, a German submarine sank the British battleships *Aboukir*, *Cressy*, and *Hogue*. On August 12, just a month and ten days before, Holland had died. He was mercifully spared the ruthless spectacle of German submarine piracy, but on the other hand he did not live to see his prophecy come true and witness the grim triumph of this most important recent invention of naval warfare. In this first notable submarine sinking of the late war (you cannot call it a battle) a British squadron was passing in stately procession before the undetected periscope of the U–9, commanded by Lieutenant-Commander Otto von Weddigen. Of a sudden he pressed the button and a torpedo sped straight to the side of the *Aboukir*. Through his periscope, the German saw the bursting shell lift the giant ship high into the air, and then watched her quietly sink beneath the sea. With characteristic British bravery, the *Hogue* swung round to the rescue, and she too was torpedoed. Then came the *Cressy* to a similar fate. The German submarine made its get-away, as stealthily as its approach, the victor in the most curious action in naval history. Yet, had it not been for the persistent efforts of John P. Holland, the submarine and all its "frightfulness" might still be but a possibility of the future.

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Holland was born in Ireland in 1841. He received sufficient education to enable him to teach in an Irish monastery, and there he worked out his plans for the submarine. This was during the time of our Civil War, and he had read with great interest and much foreboding the news of the ironclad *Monitor,* invented by Ericsson for the northern navy. The supreme ambition of Holland's life was to free Ireland from the domination of English rule. The chief obstacle in his mind was the British fleet. The coming of this new and formidable type of warship, he felt, would only strengthen British sea-power and forge more securely the chains of her dominion. Some means must be devised of combatting the English fleet. Holland's only hope lay in attacking beneath the sea. For a time he had strong hopes that the claims of the United States growing out of the sinking of northern ships by the British-built *Alabama* would result in an Anglo-American war and thus give Ireland her chance for independence. But fortunately war did not result, and Holland turned with all the enthusiasm of an intense patriotism to the invention of a submarine.

He had read Jules Verne and was acquainted with the exploits of Bushnell, Fulton, and others. A submarine seemed to him a perfectly feasible craft. In the early seventies Holland came to America. He landed in Boston, and the first important incident of his life in the new country was an illness which kept him in the hospital for a considerable period. During the long hours of convalescence, Holland got out his

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plans for the construction of a submarine and studied them over and over in great detail. He even sought financial assistance for the building of an experimental boat. In 1873 he went to teach in St. John's Parochial School at Patterson, New Jersey. There in 1875 he built his first miniature submarine, but it stuck in the mud on launching, it leaked, and its engine repeatedly broke down. His friends looked upon it as a joke. It was of the familiar cigar-shaped type, sixteen feet long and two feet wide at the middle point. Holland sat amidships and operated the propeller by pedalling. He had not failed to provide for a torpedo to be affixed to the bottom of the enemy-ship. A second boat called the *Holland No. 2* was but little improvement.

Still fascinated with the idea and believing that he was on the highway to a revolutionizing invention, Holland persisted. Becoming interested in an organization for the furtherance of Irish freedom, he was able to requisition a fund of several thousand dollars for experimental purposes. The result was two boats which demonstrated completely the correctness of his idea. Of one of these boats, Rear-Admiral Philip Hichborn of the United States Navy said:

"She was the first submarine since Bushnell's time employing water ballast and always retaining buoyancy, in which provision was made to insure a fixed center of gravity and a fixed absolute weight. Moreover, she was the first buoyant submarine to be steered down and up in the vertical plane by horizontal-rudder action as she was pushed forward by her motor, instead of being pushed up and down by vertical-acting

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mechanism. Her petroleum engine, provided for motive-power and for charging her compressed-air flasks, was inefficient, and the boat therefore failed as a practical craft; but in her were demonstrated all the chief principles of successful, brain-directed, submarine navigation. In 1881, Holland turned out a larger and better boat in which he led the world far and away in the solution of submarine problems, and for a couple of years demonstrated that he could perfectly control his craft in the vertical plane. Eventually, through financial complications, she was taken to New Haven, where she now is."

Holland's boat, unlike its predecessors, dove head-first and, instead of several minutes, required but a few seconds to reach a considerable depth. It worked perfectly in the waters about New York and was really a triumph. Holland had now given up teaching and was devoting all of his time to submarine construction. Several others followed, and by 1888 he had convinced Secretary Whitney of the desirability of adding this new fighting unit to the United States Navy. But a change of administration at Washington brought these plans to naught, and Holland failed to secure the contract for which he had hoped. His hope again rose when in 1893 the Navy Department advertised for bids for a submarine. Holland won the contract and built the *Plunger*. But technicians in the Department at Washington insisted against Holland's judgment upon many modifications of his plans, and the result was failure.

In deep disgust, Holland refunded ninety-five thou-

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sand dollars to the government, took back the boat, and built another exclusively in accord with his own ideas. Then came the ninth in line, known simply as the *Holland*. It was the first real modern submarine and a great success. The boat measured fifty-three feet ten inches in length and was ten feet seven inches deep. It had been built by the Holland Torpedo-Boat Company in Lewis Nixon's shipyards at Elizabeth, New Jersey. It would seem that this new craft had come at an opportune time, for it was launched in the spring of 1898 just after the blowing-up of the *Maine* and previous to the opening of hostilities in the Spanish-American War. But the conservatism of the authorities at Washington prevented Holland from entering Santiago Harbor and attempting to blow up the Spanish fleet. Yet the inventor demonstrated the superiority of his latest creation over any previous design. It displayed great facility in diving and manoeuvering, being able to rise to the surface and disappear within five seconds. Its cruising radius was fifteen hundred miles, and it was propelled on the surface by a fifty horse-power gasoline engine at a speed of seven knots an hour. For submerged cruising an electric motor and storage batteries were provided. Horizontal rudders placed at the stern permitted of upward and downward steering. As in modern submarines, the loss of weight resulting from the discharge of a torpedo was compensated for by immediately admitting an equal quantity of water. The crew numbered six.

In the autumn of 1900 the government purchased

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the boat and ordered half a dozen more. Under command of Lieutenant Caldwell the manoeuvers executed off Newport by this porpoise of the sea had convinced naval officers of its effectiveness. Admiral Dewey testified as follows before the Naval Committee of the House of Representatives:

"Gentlemen, I saw the operation of the boat down off Mount Vernon the other day. Several members of this committee were there. I think we were all very much impressed with its performance. My aid, Lieutenant Caldwell, was on board. The boat did everything that the owners proposed to do. I said then, and I have said it since, that if they had had two of those things at Manila, I could never have held it with the squadron I had. The moral effect — to my mind, it is infinitely superior to mines or torpedoes or anything of the kind. With those craft moving under water it would wear people out. With two of those in Galveston all the navies of the world could not blockade the place."

Holland was now on the flood-tide of success. England purchased his rights for use in her navy, and soon his company was either building submarines for every important maritime nation in the world or receiving royalties from the use of his patents. Financial success came. The story is told that a New York lawyer who had loaned Holland three hundred forty-seven dollars and nineteen cents in exchange for stock in his newly formed company saw this stock rise in value to several million dollars. In 1904 the inventor withdrew from the company and just at the beginning

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of the great struggle, which was to give so thorough a test of his new weapon of naval warfare, he died. His life and work afford a capital example of man's inventive genius applied to the evil business of war.

Simon Lake

Holland was not the only inventor who entered into competition for the honor of building the first government submarine. Simon Lake, a naval architect then living at Baltimore, submitted plans for one of the queerest crafts that naval men ever saw. The shape, the wheels of the under side, the numerous propellers and steering and stabilizing planes, gave it the appearance of a cross between the airship and the airplane of a later date. But his rival won the contract and Lake turned to the realization of his original purpose, which was the direct opposite of war.

For years Lake had been turning over in his mind the possibility of salvaging the large number of wrecked ships and valuable cargoes lying on the ocean bottom in comparatively shallow water. His idea was to build a vessel that should be able to move over the ocean bed and recover this vast treasure. His first answer to this problem was the *Argonaut Junior*, a diminutive affair and probably as odd a boat as ever sailed the sea. It was only fourteen feet long, four and one-half feet deep, and five feet wide, but it was equipped with wheels for moving over the ocean bed and through an air-lock in the bow a diver was able to step outside for salvage work. Its depth limit was

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twenty feet. By cranking the two driving wheels she could be moved over a sandy bottom.

The results of this preliminary trial were so promising that Lake was able to raise sufficient capital to built a second and larger submarine. This he did in 1897. In it he preserved the same general features that he had adopted in the *Argonaut Junior*. For propulsion both on the surface and beneath the water he used a thirty horse-power gasoline engine and solved the problem of an air supply by running a hose to a float on the surface. Her depth limit was fifty feet and she was lowered by means of a windlass and cables attached to heavy anchors, which were sunk to the ocean bottom. To rise, the buoyancy of the boat was decreased by pumping out water from the ballast tanks. Save in a few minor instances Lake did not accomplish his purpose of salvaging wrecked cargoes. He soon turned his inventive ability to the work of designing submarines for naval use. He gave to the submarine its superstructure, and many of the features which he devised are retained in the modern boat. He has built many submarines for the United States and foreign countries, and before the war he spent a number of years in Europe "designing, building, and acting in an advisory capacity in construction of submarine boats."

Lake was born in 1866 at Pleasantville, New Jersey, and although twenty-five years the junior of Holland, has exercised an influence on the development of submarine craft second only in importance to that of his distinguished rival.

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CHAPTER XXVIII

TWO MASTERS OF FLIGHT

"For I dipt into the future, far as human eye could see,
Saw the Vision of the world, and all the wonder that would be;
Saw the heavens fill with commerce, argosies of magic sails,
Pilots of the purple twilight, dropping down with costly bales;
Heard the heavens fill with shouting, and there rain'd a ghastly dew
From the nations' airy navies grappling in the central blue;
Far along the world-wide whisper of the south-wind rushing warm,
With the standards of the peoples plunging thro' the thunder-storm;
Till the war-drum throbb'd no longer, and the battle-flags were furl'd
In the Parliament of man, the Federation of the world.
There the common sense of most shall hold a fretful realm in awe,
And the kindly earth shall slumber, lapt in universal law."

Wonderfully prophetic were these lines of Tennyson, written in 1840, for the fancy of the poet has found

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substantial fulfilment in the accomplishments of the present.

On September 12, 1908, at Fort Meyer, Virginia, occurred one of the notable triumphs in the history of invention. Mr. Augustus Post, former Secretary of the Aero Club of America, thus describes the event:

"One beautiful, still morning about six o'clock, Mr. [Orville] Wright and myself left the Cosmos Club and took the car for Georgetown, where we got breakfast. We then boarded the Fort Meyer trolley and arrived on the field. Not a person was in sight, except the soldiers cleaning the guns of the field battery, but Mr. James Means of Boston came on the next car. The conditions for flight were perfect. Mr. Taylor, Mr. Wright's mechanic, got out the machine and it was placed on the starting rail. The weights were raised and Mr. Wright took his place. None of us expected anything more than a short flight down the field with possibly a circle. The machine was released, and away he went, rising higher and higher, circling when he came to the end of the field and continuing round. I had taken the time of starting and marked on the back of an envelope each circle of the field. From a position of strained attention and fixed gaze, Mr. Wright gradually became more confident and comfortable; round and round he went for fully twenty minutes, and then we began to realize that something wonderful was taking place. Thirty minutes and we could hardly believe it. Mr. Taylor came up and said: 'Don't make a motion; it you do he'll come down'; and we all stood like statues, watch-

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ing the flying man, every nerve as tense in our bodies as though we were running the machine ourselves. Mark after mark I made on the back of the old envelope — so many that I had lost track of the number; it seemed an age since the machine started, and it appeared to be fixed in the sky. We were impressed that it could circle on forever, or sail like a bird over the country, so positive and assuring and complete was this demonstration. We knew that the problem of flight by an aeroplane had been solved."

Yet this remarkable event had been wholly unheralded. There was no blare of trumpets. No reporters were present. Not even the soldiers at Fort Meyer knew that it was to occur. Although from the background of his years of patient experimentation and previous triumphs, he knew that success must be his, its realization far outstripped the dreams of Wright himself. While he was still in the air, the telephone at the fort sent the news to Washington. Reporters seized upon it. It was telegraphed throughout the land and cabled abroad. Before night the whole world was eagerly discussing this latest accomplishment of the "impossible." At the earnest solicitation of the government, Wright consented to give another demonstration. Official and unofficial Washington came out en masse. Before an audience whose enthusiasm knew no bounds, this challenger of the birds remained in the air for an hour and seven minutes. At the same time his brother, Wilbur Wright, was delighting the emotional and enthusiastic French public with exhibitions of mechanical flight. Before them the skep-

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ticism of Europe disappeared and the Wright brothers were proclaimed the true conquerors of the air.

This moment of triumph had not come by chance. The Wright brothers did not achieve the dream of the centuries without effort. In patient toil, in temporary success followed by baffling failure, only to be succeeded by a new advance, they had paid the price.

To fly like the birds and to ride the billows of the sky as we do those of the sea had been the dream of many men in many times. The balloon and the dirigible had pointed the way, but they did not really conquer the fields of air. The ardor, the peril, and the joy of the modern aviator had not been experienced. Before the Wrights began their experiments, important work had been done. Even Leonardo da Vinci, that many-sided genius of the Italian Renaissance, had endeavored to discover the secret of mechanical flight. During the last century the Englishmen, Sir George Cayley, Stringfellow, and Wenham had worked out most of the principles which govern the movements of a modern airplane. Sir Hiram Maxim spent one hundred and twenty-five thousand dollars on the problem and in 1894 launched a machine weighing four tons and driven by a three-hundred-and-sixty horse-power steam engine. This huge machine succeeded in leaving the ground, but after making a flight of only three hundred feet it was wrecked. Professor S. P. Langley, Secretary of the Smithsonian Institution, built a wonderfully successful little model, with which he demonstrated the feasibility of airplane flight. Indeed, had it not been for a defective launching

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device, which wrecked his man-lifting machine, he, and not the Wrights, might have won the honor of being the first important victor in the mastery of the air. Otto Lilienthal of Germany and O. Chanute in this country made extensive experiments with gliders. Lilienthal had succeeded in making many remarkable glides, and it was the news of his unfortunate death in one of these feats that stimulated the Wrights to investigate the possibilities of mechanical flight.

These two modern pioneers in an age-old field of human interest were the obscure proprietors of a bicycle repair shop in Dayton, Ohio. They were not college men. They were mechanics. They did not understand the mathematical principles which govern flight. They had read of the gliding experiments of Lilienthal. They had studied the movements of soaring birds. And they had flown kites. For hours at a time they would lie on their backs spying upon the hawks and buzzards as they wheeled and circled above them. They watched them run swiftly along the ground to get up speed before mounting into the air. They studied the rising currents of air upon which these feathered airplanes so frequently glide with no apparent effort for long periods of time. They read everything that pertained to flying and attempted to verify the rules set forth by their predecessors. But so contradictory were the results obtained that they deliberately cast aside as fallacious all previous so-called principles. Of course this does not mean that no one else had ever discovered anything about flying. But to the Wrights it seemed easier to start anew

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and learn by first-hand experiment. Herein lies their chief claim to recognition. They did not imitate.

Practical experiments taught them the best shape for the planes, the angles to which the wings should be warped, the correct positions and adjustments of the rudders — many of their discoveries being directly opposite to those of their predecessors. These results, however, were attained not without a prodigious amount of argument as well as experimentation, each brother combatting in a friendly way every idea advanced by the other. In speaking of this period of the inventors' career, their sister said: "To hear them argue around and knock the bottom out of each other's ideas, till at the end of three hours, you find Orv where Wil started, and Wil where Orv began, is just the killingest thing imaginable and makes them both burst out laughing; but it saves them no end of useless experiments."

Upon application to the United States Weather Bureau they learned that at Kitty Hawk, North Carolina, the winds were the steadiest and strongest of the country. There they went in October, 1900, to begin their gliding experiments. On Kill Devil Hill they set up a camp, and on the windswept sand dunes continued their study of the laws of the air. It was a slow process. Sometimes they almost lost faith. "It will take a thousand years yet, before men will be able to fly," said Wilbur one day. Still they persisted, determined to add as much as possible to the knowledge of the art. Gradually they learned to steer and balance themselves by shifting the surfaces of the

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BELL



MARCONI

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WHITNEY



RÖNTGEN



HERTZ

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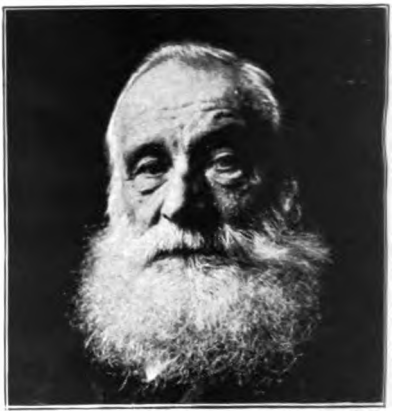
DAVY



FARADAY



NOBEL



PERKIN



WESTINGHOUSE



EDISON

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planes. The autumn of 1901 found them again at Kitty Hawk, and this time with a glider nearly twice as large as any ever used before. Their success encouraged them to build a still larger one for the following year, and with it they made nearly a thousand glides. Often it carried them above the starting-point and kept them, bird-like, soaring over the same place for as long as half a minute. Dr. Chanute of Chicago, the ablest and one of the earliest apostles of aviation in America, came to witness their flights and gave them the utmost encouragement. After the third season at Kitty Hawk, the Wrights returned to their bicycle shop, determined to build a real power machine. They had mastered the elementary principles of flight and had given to the airplane the one essential device to self-controlled equilibrium. It was the warping mechanism by which sidewise tipping is prevented and the machine kept on an even keel. This will always remain their most distinctive contribution to airplane construction. With it they had acquired greater skill than had ever before been exhibited.

In December of 1903 these intrepid brothers returned to Kitty Hawk with a machine equipped with a twelve-horse-power gasoline motor of their own construction, capable of giving a speed of thirty miles an hour. Two horizontally placed parallel planes of canvas stretched over light wood frames gave the lifting power. Rudders fore and aft enabled the pilot to steer upward or downward and to either side. At length on December 17, 1903, rising into the cold, raw air of the bleak North Carolina coast, one of the

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brothers guided this first biplane on its maiden flight. For the first time in history a self-propelled airplane had made a free flight and landed in safety. Its achievement at once ranked these modest bicycle mechanics with the great inventors. They made four more successful flights, the last one having a duration of fifty-nine seconds and covering a distance of eight hundred and fifty feet. Happy, but not unduly elated, they returned once more to their shop, knowing as Wilbur Wright said that "the age of the flying machine had come at last." Once more the "impossible" had been attained. Yet only two years before, the astronomer, Simon Newcomb, had stated that the construction of an airplane that would carry even a single man "requires the discovery of some new metal or some new force."

This event, which led to the progress in aviation of the last two decades, went unheralded for months. The Wrights did not talk about it. Neither did they make any attempt to keep their work secret. The thing just seemed too incredible for serious consideration. How could two unknown mechanics, wholly lacking in scientific training, accomplish what had proven impossible for men of the type of Professor Langley and Sir Hiram Maxim? But in the two succeeding years they quietly continued to experiment. With two new machines, they made at Dayton one hundred and sixty flights, averaging a mile each. In the last they covered a distance of twenty-four miles and were in the air thirty-eight minutes. In this work they patiently worked out the details of airplane con-

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struction and control. Then, in 1906, they patented their invention. Still they gave no spectacular demonstration, and the world remained in ignorance of their accomplishments.

In Europe some pioneer work had been done. Henry Farman, an Englishman living in Paris, had aroused the enthusiasm of the French people and won a prize of two thousand francs by flying a distance of sixteen hundred yards over a prescribed circular course, and returning safely to the starting place. This was in 1908, four years after the Wrights had accomplished far more remarkable flights. In the autumn of this year came the events at Fort Meyer and Paris, which have already been described. No longer was there any doubt as to whom belonged credit for discovering the ways of the birds and solving the problem of mechanical flight. The Wrights were acclaimed by people everywhere. Before returning to America, Wilbur Wright was visited by the kings of England and Spain, and by special request gave demonstrations in Italy and Germany. In Paris he had made the longest flight on record, remaining in the air two hours, twenty minutes, and twenty-three seconds. This was an astonishing feat and the excitable French public went airplane-mad, even as it had gone balloon-mad more than a century before.

A year later, again at Fort Meyer, Orville Wright in a never-to-be-forgotten flight met the endurance test of the United States Government. He made it before an immense throng of onlookers, chief among whom were President Roosevelt, members of Congress,

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judges of the Supreme Court, foreign diplomats, the host of government clerks, and thousands of the civilian population of the capital city. Occupying a prominent position was Katherine, the sister of the inventors. Leisurely the Wrights sauntered across the field, scanning the weather conditions and viewing the crowd. At length, feeling that the mass of eager people, many of whom had been waiting for hours, could be kept in suspense no longer, they brought out the machine. Orville Wright took his seat. The motor began to whir. Lieutenant Foulois, as passenger, climbed to his place beside him. The machine was released. Twice it circled the field to get the necessary initial speed, then passed the starting line and, amid the utmost applause, was away on its speed course. Smaller and smaller the machine grew. It disappeared from view — hidden by the trees — reappeared, turned in the far distance, and was back on its home flight. Returning over the heads of the gaping thousands, it circled the field and with all the grace of a bird landed safely near the airplane shed. It was the first public flight ever attempted over unbroken country, including numerous buildings, trees, hills, and valleys. The government had agreed to pay twenty-five thousand dollars for the machine, if it should make a speed of forty miles an hour and a bonus of twenty-five hundred more for every mile in excess of that speed. The actual speed, as determined by official time keepers, was something over forty-two miles. It was a great triumph and a fitting reward for the long years of patient toil. In October of this

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same year, Wilbur Wright, at the Hudson-Fulton Centenary Celebration, made a spectacular flight from Governor's Island over the warships anchored in the North River, up the Hudson and back to the starting point.

Wilbur Wright died in 1912, but not until he had seen himself and his brother honored by the foremost educational and scientific institutions of his own and other countries. Starting as mechanics, these brothers became self-made scientists of the highest type, worthy of the numerous academic degrees which were conferred upon them. Deeply religious, free from vanity, always striving, " the Wrights " have made an impress upon this age of human endeavor which will not be effaced.

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CHAPTER XXIX

BRIEFER BIOGRAPHIES

The selection of the eminent scientists whose names appear in the foregoing pages has frequently been difficult. In every instance the purpose has been to include those men whose work has been of fundamental importance to the progress of science and invention. There are still, however, many names which might with almost equal propriety be included. Many of them certainly deserve mention. Therefore, in this after-chapter, brief biographies will be given. The alphabetical arrangement will afford an easy means of reference.

AMPÈRE, ANDRÉ, 1775–1836. Ampère was a distinguished French mathematician, physicist, and naturalist. He is particularly remembered for his researches in electricity. Following Oersted's discovery that a current-bearing conductor has a magnetic field, he worked out more fully the relationship between electricity and magnetism. He showed that parallel conductors of electricity will repel or attract each other according as the currents flow in the same or opposite directions. In his later years he taught at the École Polytechnique in Paris. The ampere, the electric unit of current, has been named in his honor.

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ARAGO, DOMINIQUE FRANÇOIS, 1786–1853. Arago was a French physicist and astronomer who did notable pioneer work in electricity. He showed that an unmagnetized bar of iron or steel could be magnetized by an electric current. He performed the first experiment with an induced current, an experiment which he could not explain but which afforded the starting point for Faraday's epoch-making researches in this field. He also did notable work with polarized light.

ARCHIMEDES, 287–212 B.C. Archimedes passed his life in the ancient city of Syracuse and was the most famous mathematician and inventor of antiquity. He studied geometry and reduced mechanics to a mathematical basis. He explained the principle of the lever and invented the hydraulic screw. He constructed engines of war for use against the enemies of his native city. Everyone has heard the story of how he proved King Hiero's crown to be an alloy of gold with a baser metal and thereby discovered the principle of buoyancy, now universally known as "Archimedes' Principle."

ARISTOTLE, 384–322 B.C. Aristotle was the most distinguished and influential scientist of antiquity. He passed most of his life at Athens and was for three years the tutor of Alexander the Great. Much of what he taught in astronomy and physics was disproved by later scientists, particularly by Galileo. But all through the Middle Ages the dictum of Aristotle was regarded as the last word in scientific instruction, and his influence was really a handicap to the birth of modern science.

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ARRHENIUS, SVANTE, 1859–1927. Arrhenius was one of the most distinguished chemists of his time. He was born at Upsala, Sweden, and for years was a professor in the University of Stockholm. His most notable contribution to chemistry is the *theory of electrolytic dissociation* of inorganic compounds, a theory with which every high school pupil of the subject is now familiar. This theory, now regarded as proven, states that compounds capable of conducting the electric current dissociate in aqueous solution into small positively and negatively charged particles called ions and that these ions act as the carriers of the current. Arrhenius also did much important work in bacteriology and astronomy. He was awarded a Nobel prize in chemistry and served as vice-president on the Nobel Board of Trustees.

AUDUBON, JOHN JAMES, 1780–1851. Audubon was an eminent American naturalist and famous throughout the world for his exhaustive study of American birds and their beautiful portrayal by drawing and painting. He was born at Mandeville, Louisiana, his father being a French naval officer and his mother of Spanish descent. His early years were spent in France where he became expert in the use of pencil and brush. In 1798 he came to America and settled near Philadelphia on a farm, which his father gave him. For ten years his whole time was devoted to sketching and collecting birds. A number of business ventures in the West resulted in failure, and he was compelled to support his family by portrait painting. But hunting and fishing and studying birds were the supreme de-

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lights of his life. He formed the project of publishing his drawings of birds in a series of life-size colored figures. With his wife's aid he raised the money to do this, and in 1838 appeared "Birds of America" in eighty-seven parts and containing one thousand sixty-five figures. He published a description of these birds in five volumes, known as the "Ornithological Biography." In obtaining the material for this work he had traveled in all of the accessible parts of this country and Canada. In his later years, assisted by his sons, he published a volume entitled the "Quadrupeds of North America."

Audubon passed the declining years of his life in a beautiful home on the Hudson, now part of New York City. He was not a real scientist, but rather a naturalist whose work has been a perennial source of inspiration to every lover of the great out-of-doors.

BECQUEREL, HENRI, 1852–1908. Becquerel came from a distinguished French family long eminent in the field of science. The discovery of the X-rays by Röntgen suggested to Becquerel that fluorescent substances might also possess the peculiar property of giving off rays capable of penetrating opaque matter. He proceeded to investigate the subject and the result was the discovery of the radioactivity of uranium compounds. These emanations came to be called Becquerel rays. It was because of his observation that pitchblende, the mineral from which uranium compounds were obtained, exhibited a radioactivity four times greater than uranium itself that Madame

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Curie was led to make her memorable research resulting in the discovery of radium.

BLACK, JOSEPH, 1728–1799. Black was for many years professor of chemistry at the Universities of Glasgow and Edinburgh. He carried out a now classic research on the gas carbon dioxide, which he called "fixed air." His investigations with gases afforded much ground for the overthrow of the false phlogiston theory of combustion. He also developed the theory of latent heat, a subject fundamental to Watt's improvement in the steam engine.

BOYLE, ROBERT, 1627–1691. Boyle was the seventh son of the Earl of Cork and a real founder of the science of modern chemistry. For the first time he recognized the existence of many elementary substances and numerous compound bodies. He was the first scientist of note to break loose from the superstitions of alchemy and the crudities of the medical-chemists. Above all, he boldly declared that chemistry should be studied for its own sake and not because of any possible aid to the alchemist or physician. Although he recognized that a metal gains weight when heated in the air, he did not find the true explanation of combustion. He improved the air-pump and formulated the law of gas pressure which bears his name.

BRENNAN, LOUIS, 1852–1932. Brennan was the famous inventor of the mono-rail gyro car. He was born in Ireland and first came into prominence through the invention of a torpedo for the British Government.

CROOKES, SIR WILLIAM, 1832–1919. Crookes was a

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distinguished English physicist and chemist, whose name will forever be associated with the "Crookes tube." With this he did pioneer work on the discharge of electricity in high vacua and paved the way for the discovery of the X-rays. He discovered the element, thallium, and devised a new method of spectrum analysis.

DANA, JAMES DWIGHT, 1813–1895. Dana is the most noted of American geologists. He was born at Utica, New York, and died at New Haven, where he had spent the greater part of his life as professor at Yale and as editor of the American Journal of Science. As a member of the Wilkes exploring expedition to the Pacific Ocean, he collected an immense amount of zoological material, on which he worked for thirteen years. Among his writings which have passed through many editions were "Mineralogy," "Manual of Geology," "Geological Story Briefly Told," "Corals and Coral Islands," and "Volcanoes." It is interesting to know that after having opposed Darwin's theory of evolution for many years, at the age of seventy he became a strong convert of the new doctrine. Dana was a most inspiring teacher and a scientist of the old school to which belonged Cuvier, Lamarck, Darwin, Gray, Agassiz, and Humboldt.

DE FOREST, LEE, 1873– . Dr. De Forest is one of the most eminent of American engineers, particularly in the field of radio engineering. He is the inventor of the "Audion" bulb detector and the amplifier, so widely used both in long-distance telephone transmission and in wireless telephony.

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DEWAR, SIR JAMES, 1842–1923. Dewar was a Scottish chemist and professor at Cambridge and the Royal Institution who did some of the most notable work on the liquefaction of refractory gases, particularly hydrogen. He devised the "Dewar bulb," originally employed for containing liquid gases, but now universally known as the thermos bottle.

ERICSSON, JOHN, 1803–1889. Ericsson was a famous Swedish-American engineer and inventor, and an extraordinary man. In 1829 he built the *Novelty*, a locomotive which competed with Stephenson's *Rocket* for the prize offered by the Liverpool and Manchester Railway. He improved the design of steam engines and invented his "caloric engine." But he is best known as the inventor of the turreted iron-clad *Monitor* which had such a revolutionary effect upon the navies of the world at the time of our Civil War. He applied the screw propeller to steamships, devised the torpedo-boat destroyer, and experimented with solar engines.

FIELD, CYRUS, W., 1819–1892. Field will forever be remembered as the financial backer and organizer of that little group of pioneers who, against every obstacle of fate and man, laid the first transatlantic cable.

FRANKLIN, BENJAMIN, 1706–1790. Franklin was the first of American scientists. He achieved renown both in America and Europe. He experimented chiefly in the field of static electricity, in which he was a foremost worker. For his bold experiment in which he snatched the lightning from the skies and

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proved its identity with the electricity of the Leyden jar he will always be remembered. He was also the inventor of the Franklin stove and the lightning rod. He founded the American Philosophic Society, the first scientific organization in America.

GALVANI, LUIGI, 1737–1798. Galvani's name will always be associated with the words "galvanic" and "galvanism." As an Italian physician interested in the application of electricity to the human body, he accidentally discovered the existence of the electric current and performed experiments which led Volta to the invention of the electric cell.

GAY-LUSSAC, JOSEPH, 1778–1850. Gay-Lussac was a noted French chemist whose work for half a century exerted a profound influence upon the development of the subject. Working with Humboldt he announced the exact composition of water and independently discovered the law of combining gas volumes. He did important research work upon the commercial manufacture of sulfuric acid. In his Paris laboratory some of the most notable chemists of the century including Liebig received instruction. He did important early work on iodine and its compounds. In many fields he was an orginal investigator. He became professor at the Sorbonne and later at the Jardin des Plantes.

GILBERT, WILLIAM, 1540–1603. Gilbert was physician to Queen Elizabeth and James I. His studies in magnetism and electricity have given him the title of "the father of modern electricity." He was the first to discover the earth's magnetism and to explain the dip of the compass needle by the influence of the

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magnetic poles. He coined the name "pole" and was the first to use the term "electric." For the first time he distinguished between magnetism and electricity and made the first electric indicating device.

GOODYEAR, CHARLES, 1800–1860. Goodyear was an American manufacturer who discovered the process of vulcanizing rubber, thereby enabling it to retain its property of elasticity and its usefulness under varying degrees of temperature and pressure. His machine for the sewing of soles, known as the "turn-sole machine," has been of great importance.

GRAY, ASA, 1810–1888. Asa Gray was the foremost of the early botanists in this country and Professor of Natural History at Harvard from 1842 to 1888. He was one of the early champions of Darwin's theory of evolution and wrote a book in its defense. Among his published volumes are "Elements of Botany," "Flora of North America," "How Plants Grow," "Field, Forest and Garden Botany," and "Manual of Botany of the United States."

GRAY, ELISHA, 1835–1901. Elisha Gray was one of the most prolific of American inventors. Of Quaker parentage, educated at Oberlin College, possessing great mechanical ability, he early turned his attention to electricity. He was one of the original promoters of the Western Electric Company and from his many electrical inventions amassed a fortune. Two of his most notable devices were a harmonic telegraph, by which he sent as many as twelve messages over a single wire at the same time and the "telautograph," or fac-simile telegraph. The most important incident

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in his career was his long legal battle with Bell over the invention of the telephone. It has been established, however, that Gray was largely a usurper and Bell incontestably the inventor.

GUERICKE, OTTO VON, 1602–1686. Von Guericke was a German scientist who invented the first electrical machine and the air-pump. He discovered the properties of electrical attraction and repulsion. With the famous "Magdeburg hemispheres" he demonstrated the great pressure of the atmosphere.

HAECKEL, ERNEST, 1834–1919. Haeckel was the "last of the Darwinians" and one of the most able of the early defenders of evolution. He became professor of zoology at Jena and for more than half a century was one of the leading naturalists, not only of Germany but of the whole world. His book "The Riddle of the Universe" is an application of the principles of evolution to the problems of philosophy and religion.

HARVEY, WILLIAM, 1578–1657. Harvey was an English physician who won lasting recognition as the discoverer of the circulation of the blood. The truth of his demonstrations, performed on serpents, was quickly accepted everywhere. He was at one time a student under Galileo.

HOWE, ELIAS, 1819–1867. In 1845 Howe invented a sewing machine which was the forerunner of all modern sewing machines. To secure his rights he fought a long legal battle but won both the decision of the courts and financial wealth.

HUXLEY, THOMAS, 1825–1895. Huxley was an

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eminent English biologist and the foremost champion among Darwin's fellow-countrymen of the theory of evolution. Noted as professor and lecturer.

HUYGENS, CHRISTIAN, 1629–1695. Huygens was a Dutch physicist and astronomer, who invented the pendulum clock and first used the coiled balance spring in a watch. He originated the wave theory of light. With a telescope of his own construction he discovered one of the satellites of Saturn. He was the first scientist to intimate the existence of an all-pervading ether of space.

JANSEN, ZACHARIAS. Jansen was a Dutch optician of the sixteenth century who, utilizing a concave and a convex lens placed at the ends of a tube, made the first compound microscope.

KOCH, ROBERT, 1843–1910. Koch was a celebrated German bacteriologist. Coincidently with Pasteur, he studied the disease known as anthrax and announced a method of preventive inoculation. He discovered the bacillus of tuberculosis and demonstrated that the comma bacillus is responsible for Asiatic cholera.

LANGLEY, SAMUEL P., 1834–1906. Langley will forever be remembered as the foremost American pioneer in solving the problem of aerial flight with a heavier-than-air machine. With a model twelve feet wide, sixteen feet long, and driven by a one-half horsepower steam engine weighing but twenty-six ounces, he made a flight of three-quarters of a mile. But for a faulty launching device, he would have achieved the triumph of flying with the first successful man-

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carrying machine. Langley was an astronomer and secretary of the Smithsonian Institution.

LODGE, SIR OLIVER, 1851– . Lodge is one of the most distinguished of English physicists. He has done much original work on radioactivity and the structure of the atom. In recent years he has devoted much tme to psychic phenomena.

LYELL, SIR CHARLES, 1797–1875. Lyell was an apostle of the new geology. He opposed the old idea that great natural catastrophes had marked the divisions between the epochs of geologic time. He taught that the earth had come to its present form and state through slow processes of change exactly similar to those in operation now. He was one of the earliest converts to Darwin's theory of evolution and an able defender of it.

MAXWELL, JAMES CLERK, 1831–1879. Maxwell was a noted Scotch physicist who is remembered for many important researches but most of all for his demonstration of the electromagnetic nature of light. He showed that light waves differ from heat and radio waves only in length, or pitch.

MENDEL, GREGOR, 1822–1884. Mendel was an Austrian priest who, having been trained in mathematics and the sciences, devoted much time to problems of heredity among animals and plants and evolved a new theory known as "Mendelism." Mendel in his first experiments crossed various varieties of peas and noted the inheritance in successive generations of particular characters. As a result of these and many other experiments, he arrived at

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certain laws of heredity which are the basis of a new branch of biology known as genetics. His theory was wholly neglected during his life-time and Mendel died a disappointed man, but it was rediscovered in 1900 and has since been given great prominence.

MICHELSON, ALBERT A., 1852–1931. One of the most distinguished of American physicists. He was head of the department of physics of Chicago University for many years. He carried out accurate determinations of the velocity of light and wrote a book upon this subject. One of his most notable achievements was the measurement of the diameter of the star Betelgeuse, which he found to be three hundred and twenty-seven times as great as that of our sun. In 1907 he won the Nobel prize in physics. In 1926 he announced his most recent determination of the velocity of light as 299,786 kilometers or 186,284 miles per second.

MOISSAN, HENRI, 1852–1907. Moissan was a French chemist who first conceived the idea of utilizing the tremendous heat of the electric arc for the production of chemical changes. He made the first electric furnaces. His most notable achievement was the production of artificial diamonds by the sudden cooling of molten iron in which he had dissolved carbon. He was for many years professor at the Sorbonne.

OERSTED, HANS CHRISTIAN, 1777–1851. Oersted was a Danish physicist at the University of Copenhagen who discovered that a current-bearing conductor possesses a magnetic field and when placed over and parallel to a compass needle will deflect it. This was

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the opening wedge which led to the electrical researches of Ampère, Arago, and Faraday.

PARACELSUS, PHILIPPUS AUREOLUS, 1493–1541. Paracelsus was the leader in the movement which turned the study of chemistry from the pursuits of the alchemists into the search for drugs and medicines for the curing of human disease. For a time he exerted a wonderful influence upon the course of chemical development.

PROUST, LOUIS JOSEPH, 1755–1826. Proust in a memorable scientific controversy with his distinguished fellow-countryman Berthollet proved in a series of exhaustive experiments that the composition of a chemical compound never varies. This fact is known as the "Law of Definite Proportions" and is familiar to every pupil of chemistry.

RAMSAY, SIR WILLIAM, 1852–1916. In one of the most notable researches of the last century, Sir William Ramsay discovered the five rare gases of the atmosphere, *argon, helium, neon, krypton,* and *xenon.* He was led to this investigation from the fact discovered by his colleague Lord Rayleigh, that nitrogen obtained from the air is persistently heavier than nitrogen obtained from chemical sources. This resulted in the discovery of argon and later of the other four. By means of the spectroscope, Sir Norman Lockyer in 1867 had discovered helium in the atmosphere of the sun, and Ramsay found it in rocks of the earth before he obtained it from the atmosphere. Together with Professor Frederick Soddy, Ramsay was a pioneer in the investigation of radioactivity.

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RICHARDS, THEODORE W., 1868–1928. Theodore William Richards, who was Erving Professor of Chemistry and Director of the Wolcott Gibbs Memorial Laboratory at Harvard University before his death, was the foremost of American chemists, as well known in Europe as in America. His most important work was the determination of the atomic weights of a large proportion of the chemical elements with an accuracy up to that time unapproached. He regarded these numbers as the "most significant set of constants in the universe."

RUMFORD, COUNT, 1753–1814. Rumford was an American royalist and soldier of fortune who forsook his native country and became prominent in the military circles of Europe. He will always be remembered as the Founder of the Royal Institution in London where Davy and Faraday carried out their immortal researches. In boring cannon for the defense of Munich, he discovered that heat is a form of motion.

RUTHERFORD, SIR ERNEST, 1871– . Rutherford was professor of physics at McGill University, Montreal, for a number of years. In 1908 he became Langworthy Professor of Physics and Director of the Physical Laboratory at the University of Manchester. Since 1919 he has been Cavendish Professor of Experimental Physics and Director of the Cavendish Laboratory at the University of Cambridge. He is a foremost investigator of radioactivity and the structure of the atom. Much of the recent notable advance in these fascinating and important fields of research has been due to discoveries made by him.

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TESLA, NIKOLA, 1857– . Tesla invented the system of alternating current power transmission and the induction motor. He has been a pioneer investigator of high frequency currents and systems of radio communication. He is at present largely engaged on the problem of the wireless transmission of electric power.

THOMSON, SIR J. J., 1856– . Thomson is the most distinguished of living English physicists. His most important investigations have been in the fields of electricity and magnetism. He discovered the electron, the ultimate negative unit of electricity, and determined its mass. In 1905 he was appointed professor of physics at the Royal Institution. Previous to that time he had been Henry Cavendish Professor of Physics at Cambridge. He is now Master of Trinity College, Cambridge.

TYNDALL, JOHN, 1820–1893. Tyndall was a great popularizer of scientific subjects. His works on heat, light, and sound have become classic, and his lectures were both entertaining and instructive. He was one of the early and most ardent of the champions of the Darwinian theory. He was a thorough student of glacier phenomena and wrote extensively upon this subject. He will always be remembered as one of the most gifted and popular of English physicists.

VAN'T HOFF, JACOBUS HENRICUS, 1852–1911. Van't Hoff was one of the greatest of physical chemists. He passed his life as a student and professor in universities of his native country of Holland and those of Germany and France. His most notable contribution

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was the founding of a new branch of organic chemistry known as stereochemistry and having to do with the structure of the molecules of carbon compounds.

VIRCHOW, RUDOLF, 1821–1902. Virchow was a great master of pathology, or the science of disease, and the founder of cellular pathology. He was a German and a leading physician, anatomist, and anthropologist.

VOLTA, ALESSANDRO, 1745–1827. Volta's name will forever be associated with the "voltaic current," and the "voltaic pile" which he invented. The latter was the first electric cell ever constructed and was so named because it consists of alternate discs of two different metals, such as tin and silver, and separated from each other by discs of porous paper soaked in vinegar. One set of discs was positive and the other negative. We today can hardly appreciate the scientific ferment which this simple discovery created. It set the whole philosophic world to speculating upon the nature and future possibilities of the new-found "influence." Volta was an Italian physicist.

WALLACE, ALFRED RUSSEL, 1822–1858. Wallace was a fellow-countryman of Darwin and simultaneously with him announced the theory of natural selection. This incident affords one of the most striking coincidences in the history of science. There seems to be no doubt, however, that Darwin made his announcement privately a year in advance of Wallace and is clearly entitled to priority. Certainly Wallace did not develop and defend the theory as Darwin did.

WHEATSTONE, SIR CHARLES, 1802–1875. Wheat-

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stone was the inventor of the English telegraph and an eminent British investigator in the field of electricity.

YOUNG, THOMAS, 1773–1829. Young is chiefly remembered for his discovery of the law of the interference of light, which led to the establishment of the wave theory. He was an all-round English scholar. His work on Egyptian hieroglyphics led to their decipherment. Long after his death his theory of color-sensation was developed by Helmholtz.

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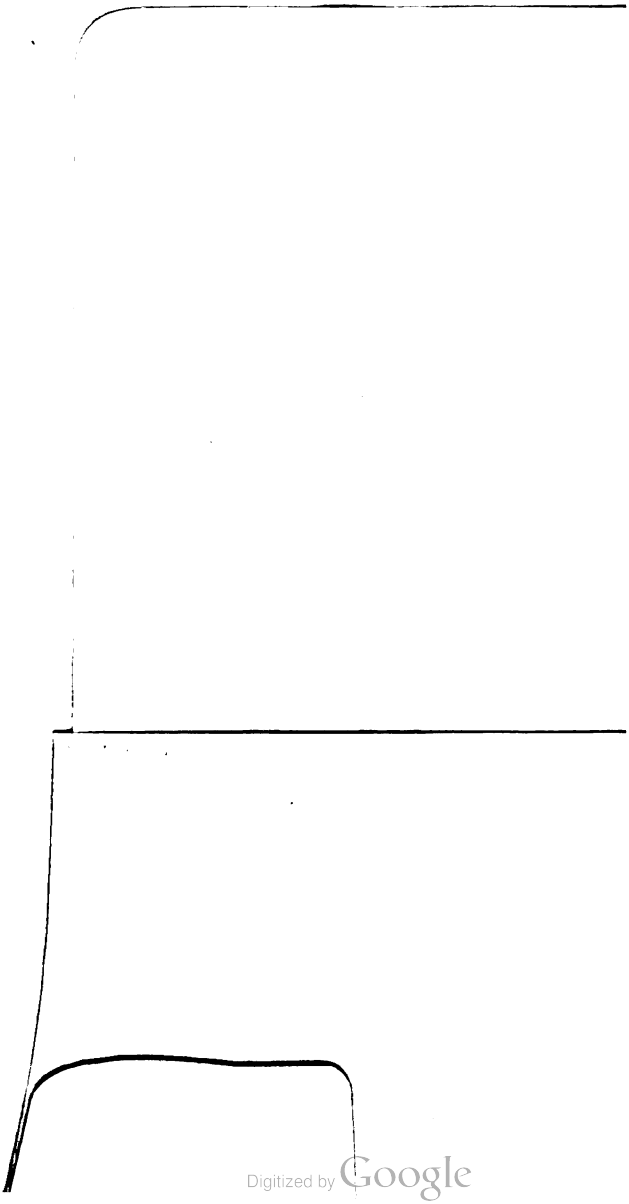
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